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Aquaponics NOMA

New Innovations for Sustainable Aquaculture in the Nordic Countries



Aquaponics NOMA (Nordic Marine)

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in the Nordic Countries*

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*– New Innovations for Sustainable Aquaculture
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Project 11090

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Abstract

The main objective of AQUAPONICS NOMA (Nordic Marine) was to establish innovation networks on co-production of plants and fish (aquaponics), and thereby improve Nordic competitiveness in the marine & food sector. To achieve this, aquaponics production units were established in Iceland, Norway and Denmark, adapted to the local needs and regulations. Experiments were performed to investigate suitable fish and crop species for Nordic aquaponics in terms of growth, quality, effluents, temperature and nutrient balances. Further efforts have been made to optimize management practices and technologies in aquaponics, e.g. treatment of wastewater and solid wastes to protect the environment from pollution and pathogens. The project has designed commercial scale aquaponics production models for the Nordic region, and investigated consumer market potentials including the possibility for Eco-labeling. The study has demonstrated that aquaponics may be a viable component in Nordic food production, both at small scale (urban aquaponics) and in large scale combinations of agri- and aquaculture. The results have been and will be disseminated to the public and to the scientific community.



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Preface & acknowledgments

In 2012, the participants of the project decided to connect with a Canadian research team in aquaponics, in order to share knowledge and experience. It has been a pleasure to cooperate with Dr Nick Savidov from The Government of Alberta, Canada, and the project consortium would like to thank him for his contributions at several Skype-meetings, and for his sharing of knowledge and experience with aquaponics in Canada.

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Last, but not least, we would like to thank Dr Randi Seljåsen from Bioforsk for her critical commenting and many good suggestions to the report.

On behalf of the project consortium

Grimstad, May 2015

Siv Lene Gangenes Skar, Bioforsk

Executive summary

This report provides an analysis and evaluation of the current state and the future possibilities of Nordic aquaponics, as a new way to produce food locally and sustainable. The analysis includes an economic and technical analysis as well as system design, selection of suitable plant- and fish species, investigations on plant to fish ratios, documentation of growth of fish and plants. The results show that it is possible to develop aquaponics systems suited for Nordic conditions. In order to fulfil requirements in national legislations or the companies' strategies, different system designs were used in the different countries.

The report finds the prospects of Nordic aquaponics positive as a new way to produce healthy vegetables and fish locally by using fish wastewater as a nutrient supplier. The discussion includes benefits of aquaponics food production:

- Extremely water efficient
- Does not require soil
- Does not use any chemical pesticides or fertilizers
- Daily tasks, harvesting and planting are creating job opportunities and can include all genders and ages
- Can be used on non-arable land such as deserts, degraded soil or salty, sandy islands
- Sustainable and intensive food production system
- Two agricultural products, fish and vegetables, are produced from one nitrogen source, fish feed
- Organic-like management and production

The work has also revealed some areas of weakness, which requires further investigation and remedial action by R&D institutes and know-how companies. Discussion points include:

- Improving system design for optimal production of fish and plants
- Legislation in the Nordic countries for aquaponics start-ups
- Parameters to improve/increase investors/producers turnover
- Fish and plant requirements do not always match perfectly
- Knowledge on fish, bacteria and plant production is needed for each farmer to be successful
- Expensive initial start-up costs compared with soil vegetable production or hydroponics
- Daily management is mandatory

- Energy demanding
- Requires reliable access to electricity, fish fingerlings and plant seeds
- Mistakes or accidents can cause catastrophic collapse of the system
- Reduced management choices

Before starting an aquaponics production, it is necessary to consider:

1. Where is the aquaponics facility going to be placed, water availability, legislation (Mattilsynet in Norway, the Environment Agency and Local Municipalities in Iceland and Denmark), fish fingerlings, energy, choice of crop, etc.?
2. Do I have the required knowledge? If not, where can I find information about this?
3. Do I have required licences for fish farming (concession, fish welfare course, etc.)?
4. Can I sell my products? Ask authorities for food safety (Mattilsynet in Norway, the Environment Agency and Local Municipalities in Iceland)
5. Make an analysis of your market – to whom are you selling the products?
6. Enjoy your aquaponics production – there will always be a learning period in the beginning of a start-up!

The project participants recommend continuing the work with aquaponics and sustainable production methods within the blue-green sector. This project aims to understand the importance of common knowledge, collaboration between companies/consumers/researchers and those innovation products needs new research. Companies' needs more knowledge for construction of new system modules to make local food rural or urban and job-opportunities to younger or un-employed people. Aquaculture and horticulture production sites need manuals to understand how to combine



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1. Introduction

Combining traditional aquaculture with hydroponics (where plants are cultivated in water given liquid chemical fertilizers), are defined as aquaponic systems and are known as sustainable systems. Effluents from the aquaculture are utilized as nutrients for the plants in the hydroponics (water culture), thus creating a symbiotic natural environment with maximum utilization of all raw materials and waste (Nelson & Pade, 2008). Well-balanced aquaponic systems are easier to operate than hydroponic systems or recirculating aquaculture systems (RAS) because of the system building up a flora of microorganisms that works for the system balance and usually aquaponics have a wider safety margin for ensuring good water quality (Nelson & Pade, 2012). The systems can contain fresh water with production of herbs, vegetables or fruits, or salt water with focus on algae production.

Even if the aquaponic science is still in its early stage, some commercial units are available, e.g. in USA, China and Africa and a rapid development is now going on with Aquaponic companies being established in many countries, such as Norway, Denmark, Iceland, UK, Switzerland and Spain. For warm freshwater systems with tilapia, sufficient knowledge are available within plant selections, technology, system designs, etc.

Aquaponics is a designed version of the ancient techniques our ancestors used in natural lakes or other well irrigated landscapes to produce food (figure 1.0-1). Today, aquaponics recognizes as one of the most exciting and productive food systems.





Figure 1.0-1:

Chinampas in ancient Mexico, picture: <http://incredibleaquagarden.co.uk/media/chinampa1.gif>

The system was re-discovered in early 1970 by some visionaries. In the beginning of 1980, Dr. James Rakocy (with a PhD degree in aquaculture) started his career at the University of the Virgin Island (UVI) in USA, where his main mission was to develop aquaponics technology. Today, the commercial-scale UVI aquaponics system, based on tilapia and different vegetables and herbs, is still a good model for future development in aquaponics systems for commercial production all over the world.

1.1. Introduction to the aquaponics system

Aquaponics is a synergistic production technique where you grow fish and plants together in the same system (fig. 1.1-1). The water discharged from the fish production, feeds the growing plants using organic hydroponic techniques. The plants, in turn, clean and filter the water that returns to the fish environment. Although in use since the 1980s, aquaponics is still a relatively new method of food production with only a small number of research and practitioner hubs worldwide with comprehensive aquaponics experience.

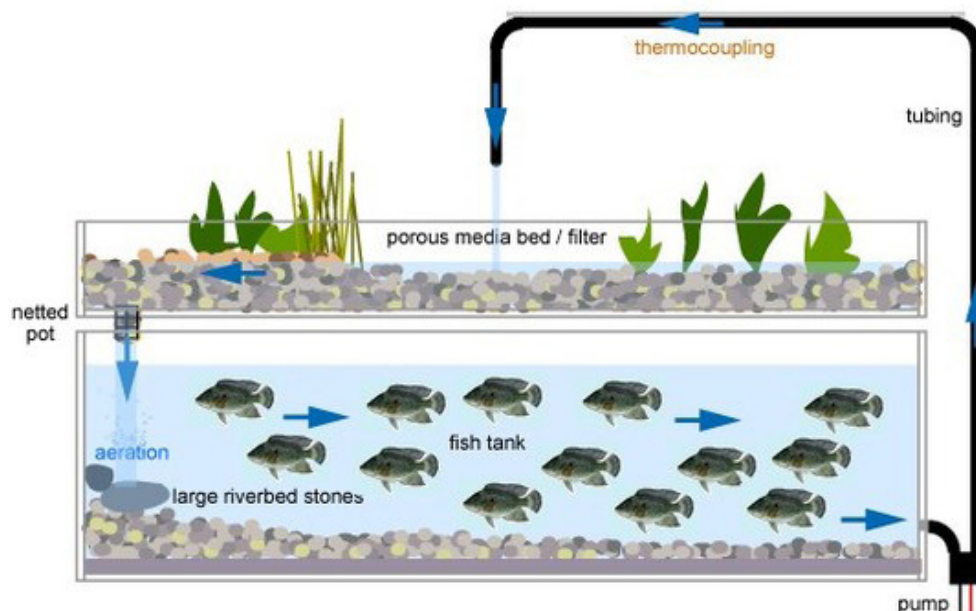


Figure 1.1-1:

A typical aquaponic system design, where fishes are fed normally and extract ammonia into the water, water is pumped up to plant grow-bed where plant roots absorb nutrients and water, and water drips back to the fish through porous media bed/filter (Aquaponicssystems, 2012).

Fish feed provides a steady flow of nutrients into the aquaponics systems, which makes the addition of hydroponic nutrient solutions unnecessary. In aquaculture, up to around 70-75% of the feed goes to waste in solid, dissolved or gaseous form (Rakocy & Hargreaves 1993). Consequently, nutrient concentrations in closed recirculating systems, with less than 2% water intake, can reach levels similar to those in hydroponic nutrient solutions.

Investigation of nitrogen transformations in warm-water aquaponics in tomato (*Lycopersicon esculentum*) and pak choi (*Brassica campestris*), showed that nitrogen utilization efficiencies (NUE) of tomato- and pak choi-based aquaponics systems differed by nearly 7%, in favour of tomato systems. The abundance of nitrifying bacteria in tomato-based aquaponics was more than 4-folds higher than in pak choi-based aquaponics, primarily due to its higher root surface area. In addition, about 1.5-2% of the nitrogen input were emitted to the atmosphere as nitrous oxide (N_2O) in these systems. (Zhen Hu *et al*, 2015).

Build-up of nutrients within recirculating systems mainly consists of nitrates and phosphates. Hydroponics provides an effective way of removing these nutrients, eliminating the need for expensive biofilters (Rakocy *et al.* 2006). The waste removal system in aquaponics units consist of a few basic elements. First, a clarifier or a swirl separator removes suspended and particulate solids. After that, the water flows through the hydroponic unit where dissolved nutrients, are absorbed by plant roots. Bacteria living on the sides of tanks, pipes and the underside of hydroponic rafts further remove ammonia. Finally, the effluents from the hydroponics collect in a sump (reservoir) and pumps back into the fish tank (Rakocy *et al.* 2006).

Aquaponics can be a sustainable and healthy way to grow vegetables and other plants, when utilizing effluents from aquaculture to hydroponic plant production. To have a system in balance – which is very important for an optimal production – the most secure way is to build floating rafts with a high volume of water.

There are environmental factors to control, like temperature and quality parameters of water, the air in greenhouse and ventilation (emission), and amount of light, insect intrusion, diseases and pollution (discharge, effluent, waste). What you cannot control, is the variation in concentration of nutrients and which nutrients are available for plant growth.

The process known as photosynthesis makes plants able to break down carbon dioxide CO_2 and turn it into oxygen O_2 and sucrose (figure 1.1-2). In order to be able to carry out this process, and grow and reproduce, the plants need nutrients. The organic matter dissolved in the water that comes from the fish tanks, contains nearly 99% of all the nutrients they need for growing. The photosynthetic reaction is:



Another important process is the nitrification reaction (figure 1.1-2). Aerobic bacteria can use reduced inorganic nitrogen as electron source and bicarbonate as a carbon source. The reaction includes ammonia oxidizing bacteria (Nitrosomonas, Nitrosococcus, Nitrospira, Nitrosolobus, Nitrosovibrio) and nitrite oxidizing bacteria (Nitrobacter, Nitrococcus, Nitrospira) which converts ammonia (NH_3) into nitrite (NO_2^-) and nitrate (NO_3^-). Nitrate uptake and reaction by plants, where it is used in the construction of chlorophyll and amino acids. Nitrite is toxic to animals and plants, and the process to convert further into nitrate is important. Neither nitrite nor nitrate can be bound in the soil, so both will follow water movement. The transformation of ammonia to nitrite is usually the rate-limiting step of nitrification. These aerobic reactions are:



Nitrogen is necessary for all known forms of life on Earth, and is a component in all amino acids, incorporated into proteins, and nucleic acids like DNA and RNA. Nitrogen gas (N_2) is the largest constituent of the Earth's atmosphere.

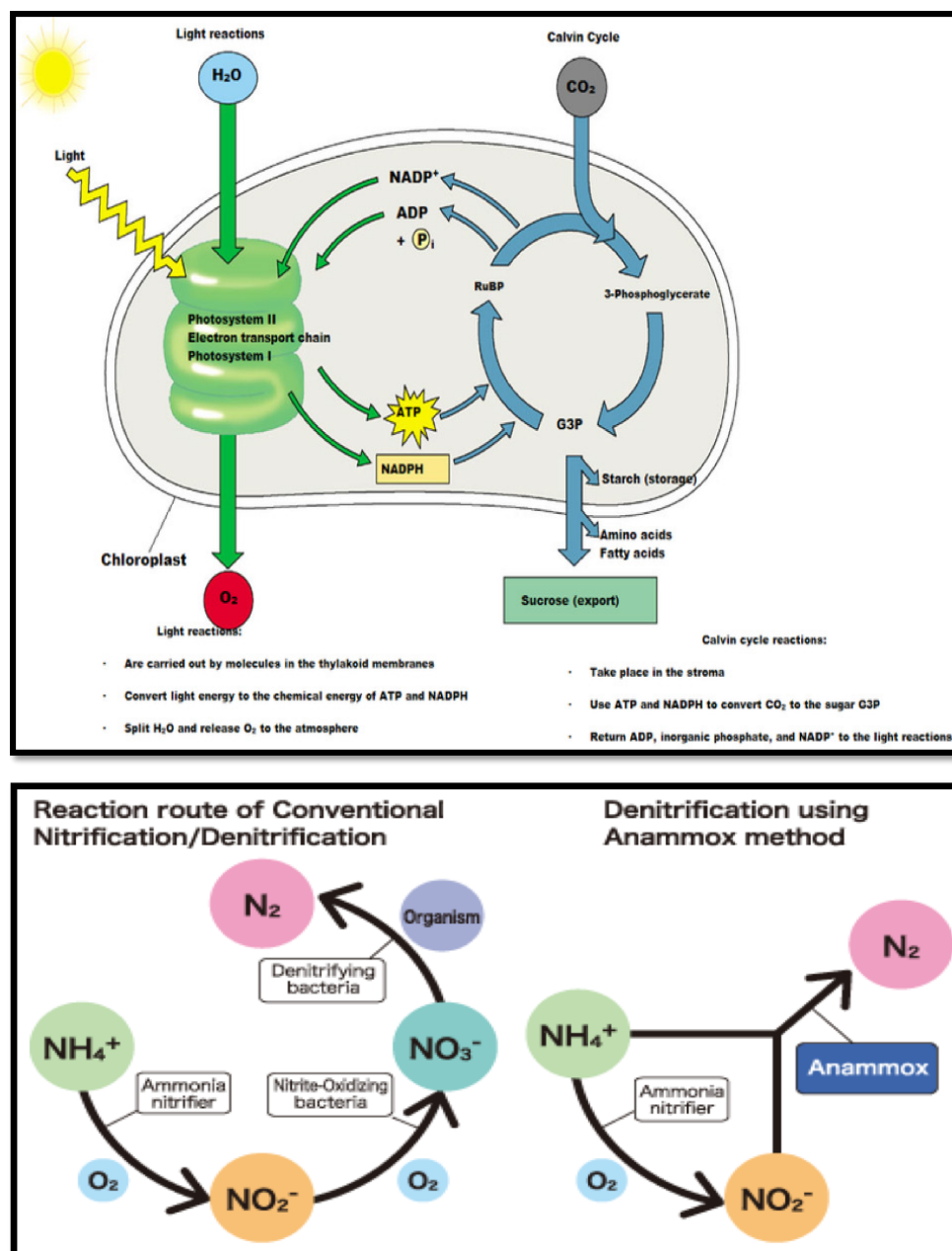


Figure 1.1-2:

The photosynthetic reaction in a plant cell (Bioap Wiki-space, 2010) and the nitrification process (GESAP, 2007).

Plant production systems

Gravel beds (fig 1.1-3 a) are often used in different aquaponic systems for use in backyard systems. These beds are good to maintain the good bacteria work for biofiltration, nitrification and efficient plant growth. The wastewater from the fish will ebb and flow in these beds and do have a high ability to mineralise, dissolve and treat solids from fish water. However, if the fish to plant ratio are too high, gravel beds can clog and lead to toxic (anaerobic) conditions that can kill both fish and plants.

Another way to grow plants is nutrient film technique, also called NFT (figure 1.1-3 b), and

floating beds (figure 1.1-3 c). All these systems contains water.

Floating beds (fig. 1.1-3 c) are, in the opposite of NFT, very stable systems due to a high water amount, with control of pH, water temperature, dissolved nutrients, etc. In systems with a great volume of water (rafts), the water quality will need time to change, but a NFT system with less water will change more rapidly, especially due to temperature and pH.

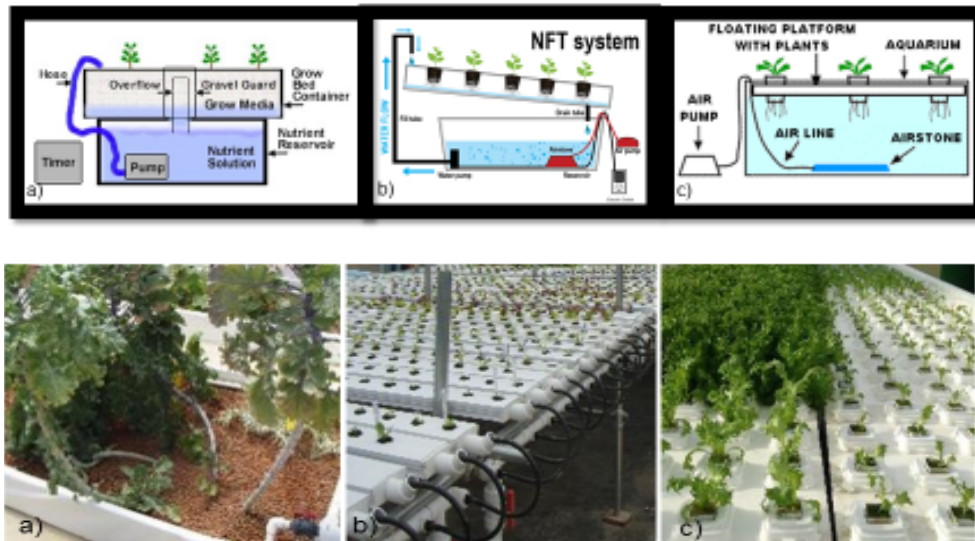


Figure 1.1-3:

a) Gravel beds b) NFT c) Floating beds. System b) and c) contain only water. System a) contain gravel. Photos: Siv Lene Gangenes Skar, Bioforsk/NIBIO.

The main objective of cultivating plants in an aquaponics system is to remove or absorb the organic matter dissolved in the water, often coming from overfeeding the fish and fish faeces. Knowledge on the ability of the plants to take up dissolved nutrients in fish wastewater is now beginning to materialize. To have normal plant growth, plants need different amounts of macro- and micronutrients and optimal growth conditions.

1.2. Aquaponics in a global context

Aquaponics has a long story globally. The story tells about natives in Mexico who produced their vegetables on floating islands in lakes with fish, using the mud of the lake for growth media. In time past, civilizations in both Asia and South America applied this method, by using faecal waste and fish excrements to fertilize plants, has existed for millennia. Around the world, aquaponics activity divides into small-, medium- and large-scale and there are few reliable system suppliers. Most of the systems are do-it-yourself systems.

America, Hawaii and Canada

The 1980s and 1990s saw advances in system design, bio filtration and the identification of the optimal fish-to-plant ratios that led to the creation of closed systems that allow for the recycling of water and nutrient build-up for plant growth. In its early aquaponics systems, North Carolina State University (USA) demonstrated that water consumption in integrated systems was just 5% of that used in pond culture for growing tilapia. This development, among other key initiatives, pointed to the suitability of integrated aquaculture and hydroponic systems for raising fish and growing vegetables, particularly in arid and water poor regions [the Food and Agriculture Organization of the United Nations (FAO)].

Dr. James Rakocy, known as the father of aquaponics concept, became interested in this way of producing and set up the first aquaponics production system we know of in USA, at the University of Virgin Island (fig. 1.2-2). After some years, Dr. Nick Savidov came to learn about this new technique for plant production, and Dr. Savidov developed further the idea of this system for Canadian conditions, and built a system inside a greenhouse (figure 1.2-2). He developed several generations of the system, and has given valuable inspiration for new system designs for Nordic aquaponics.



Figure 1.2-1:

Many ways to set up an aquaponics system, here in Hope Center in Macomb County, Michigan, USA. Source: Crain's Detroit Business, 2014.

In Canada, aquaponics is taking off as a teaching tool. A number of schools have purchased Dr. Nick Savidov's mini aquaponic set up, which he developed as a research tool. They are using this to demonstrate to school students some of the simple principles of ecology and biology.

Asia, Australia, New Zealand and Bangladesh

Dr Wilson Lennard, Murray Hallam, Dr Mike Nichols produces key calculations, production plans and workshops on commercial aquaponics system design and small business development strategies for other types of aquaponic systems. Mohammad Abdus Salam of the Bangladesh Agricultural University furthered the field in home-scale subsistence farming with aquaponics.

These research breakthroughs, as well as many others, have paved the way for various practitioner groups and support/training companies that are beginning to sprout worldwide.



Figure 1.2-2

Dr Nick Savidov (Alberta, Canada) with basil crop and fish tanks in background. Photo: Dr Mike Nichols. Source: Practical Hydroponics and Greenhouse, 2008. Second picture shows UVI system developed of Dr James Rakocy, which inspired Dr Savidov.

Rural farming

One example is in Africa, where the aquaponics specialist, Edward Nyaga, helps “Kilimo Biashara – Aquaponics Farming” (*#kilimo biashara*) and Catherine Githaiga, Daniel Kimani and Faida Yake (*aquaponics farmers*) to design and do the setup their greenhouse aquaponics system containing catfish, tilapia or trout and strawberry, chards, lettuce, mints, spices and other herbs, in a closed system. They use a greenhouse to control the temperature, monkeys, bugs etc., which can eat the crops and destroy the plants. Kilimo Biashara plans to spread the system to Kenya, Tanzania, Rwanda and Uganda. The system is designed with fishponds in the ground, vertical growth pipes with growth media (*coco peat made of coconut husk*) and plants where the water trickles from the top of the pipe and down to the fishpond. They use only organic pest control and fertilizers. In the ground, they use pumice for draining and biofilter.



Figure 1.2-3:
Many ways to set up an aquaponics system, here at Kilimo Biashara in Kenya, Africa.

Urban farming In Europe

In Switzerland, Roman Gaus and Andreas Graber founded “Urban Farmers” in Zürich. Their vision was to transform urban wastelands (including rooftops) into small-scale agricultural oases. In summer 2012, Swiss Urban Farmers opened Europe’s first rooftop farm in Basel. Here, the natural symbiotic relationship between fish and plants is exploited to the maximum, yielding up to 5 tonnes of vegetables and 800 kilos of fish per year.



Figure 1.2-4:
Aquaponics concept used in Swiss urban farming innovated by Gaus and Graber. Source: Urban Farming, 2012.

In the Netherlands, the Greenhouse Improvement Centre at Bleiswijk tried to have fish and tomatoes in the same system in project EcoFutura. Fish tanks were held inside the greenhouse, below hanging troughs with tomato-plants in Grodan Rockwool. However, this was not a full recirculation system, and the nutrient stream from the fish was sterilised with ultraviolet light before it was used on the tomatoes, and at the same time the solution was analysed, and pH adjusted, and other nutrients added to suit the tomatoes. Similarly, many of the organic solids were removed and dumped. The drainage was returned to the fish tanks, but was again modified (by increasing the pH) to suit the fish in the system, tilapia (figure 1.2-5).



Figure 1.2-5

Fish and tomatoes – Bleiswijk, Netherlands. Photo: Dr Mike Nichols Source: Hydroponics, aquaponics revisited.

1.3. Description of aquaponics activity in the Nordic countries

In the Nordic countries, there were not much information or ongoing aquaponics activity, until some years ago. Today, the interest is increasing, and during the project period, there have been several meetings and workshops in all the three collaborating countries.

In Norway aquaculture and land-based recirculating aquaculture systems (RAS) is still considered as new technology, and aquaponics is still in its infancy. During the latest years, R&D and knowhow companies have joined forces to arrange workshops and meeting points, to give information to authorities, stakeholders, researchers, costumers, educators, farmers, etc., and now we can see an increasing interest in aquaponics as a food production concept for a sustainable future.

In Iceland there is already a considerable use of the hydroponic technology within the greenhouse horticulture industry. Some of these companies have shown interest in integrating fish farming into their operation but none has done so yet. They are following with keen interest what is happening in the research arena in this field.

In Denmark like in most places of the world, Aquaponics can broadly be divided into two type of approaches: 1) a professional market- and research oriented approach, and 2)

a hobby-oriented based on a variety of DIY systems, which is the most common approach within the aquaponics field. The latter is often found in connection with in urban farming. However, the hobby approach is also being influenced by a new younger generation from a broad range of educational backgrounds designing various types of apps or installing simple computer programs to control and run their small systems. Two examples of such would be 'Plantelaboratoriet' and 'Otilias Have'. Both are placed in Copenhagen and started out by young people with university degrees within the humanistic and technical faculties, and have been supported by the Ministry of Environment. Within the professional and research oriented line IGFF is still the only one operating an aquaponics production system.

1.4. The economy of aquaponics

Serious studies on the economics of aquaponics are almost zero, and the ones that exist are often narrative based. Another weak point is that conclusions are often closely related to specific production systems growing specific types of fish and plant cultures. This makes it difficult to compare economic performances among aquaponics systems, as well as identifying 'windows of opportunity' when prices on the fish or horticultural product examined, changes.

Likewise, despite the many talks on the various symbiotic effects of aquaponics, the system also creates a dependency, and so increases the economic risks of the producer engaging in aquaponics production if a failure in one of the two biological systems should occur. For these reasons, aquaponic still performs at a smaller scale, and often built around do-it-yourself systems where the products are catering for flexible small bulk local markets.

However, if one is to see the growth of aquaponics, not only in the number of producers, but also at a level on a more industrial fashion and scale, the economics has to be more visible and scientifically based.

To commence such process of visibility the contribution margin accounting (the results of subtracting all variable expenses from revenues, and indicate the amount from sales to cover the fixed expenses and profit) is a good way to start. It creates visibility on the various costs, as well as on what conditions the income is based (Adler et al, 2001). In the following, the various contribution margins from the aquaponics systems in the project will be present.

Use of aquaponics systems has been subject to increasing interest in recent years due to a general interest in sustainable production methods, to reduce the use of non-renewable resources and combat climate change. From a purely economic point of view, aquaponics production has the advantage of utilizing nutrients from the fish production as fertilizers in the plant production. The economic value of these nutrients is however, relatively small compared to the additional costs of making them available to the plant production. In aquaponic production you need expertise on both fish- and plant production, and the optimization of a combined production is complicated. This makes it difficult to make aquaponics production competitive to traditional commercial fish and plant production. It is therefore important to include the additional value a product can have when produced in an aquaponics system, a value related to the sustainability and other characteristics of the production.

Consumers may be willing to pay a premium for aquaponics products based on the sustainability and lack of use of artificial fertilizers, parallel to the additional price on "organic" or eco-labelled products.

Local communities, particularly in urban areas, may be willing to pay a premium for locally produced food including educational and recreational values. "Urban farming" is a concept based on this.

Society may be willing to pay subsidy to support development of more eco-friendly productions, just as subsidies on organic productions or renewable energy.

Aquaponics production is still at a stage comparable to wind mill electricity production 30 years ago, with small mills that were not able to compete directly with electricity generated in traditional power plants. It was however realised that the need for climate friendly, sustainable productions makes it necessary to invest in the development of renewable energy sources. Today renewable energy is close to being commercially competitive to traditional energy production. Both “organic” farming and windmill energy has grown from being small-scale niche product to be large-scale commercial productions. It is expected that aquaponics production will develop likewise. It is therefore important to be first-movers in this process in order to be able to exploit the innovation potential.

1.5. Description of activity in the project - need of development in aquaponics

The project started in 2012 with participants from Norway, Denmark and Iceland. The aim has been to combine efforts in the three countries to strengthen their respective national projects and provide an opportunity to learn from each other. The projects initial phase has been all about testing and gathering information, and the results have so far been groundbreaking.

The project was organized in work packages focusing on fish, plants, technology and business designs. Each participating country had a SME and a research institution participating in the project.

The project has aimed at maintaining national identity. This means that different types of fish are used. The Icelandic project partner uses Egyptian tilapia in their production and geothermal heat and pumice as bio-filter substrate in their facility. In Norway, the project uses local brown trout and rainbow trout in the production system, commercial electricity from waterfalls and recirculating techniques from Norwegian aquaculture systems and farms. In Denmark, “green farming” is a part of Copenhagen municipality’s political goal of becoming CO₂ neutral in 2025. - The Danish project has a future goal, to build an aquaponics facility on a roof-top, with a café next to it. Here you will be able to enjoy a Danish local fish together with fresh vegetables produced at the same place.

In the aquaculture industry, one of the main problems is wastewater discharge from the fish. In Aquaponics the systems utilizes this waste and therefore dumps neither waste nor emissions into nature. Plants requires many different nutrients for growth e.g., nitrogen, phosphorus, carbon, potassium and calcium. Therefore, the vegetables acts like a large bio-filter in the aquaculture system. Trials have shown that some vegetables performs better than other does in cold-water aquaponics system.

The project has achieved to establish the concept of Aquaponics in Nordic region, and through a targeting professional network, our region is starting to be known for our expertise in cold-water aquaponics in Europe. During the project, our concepts have been discussed with pioneers in field: Dr James Rakocy (Virgin Island, US), Dr Charlie Schultz (US, CA), Dr Nick Savidov (CA), Dr Mike Nichols (NZ), Dr Wilson Lennard (AU) and Mr. Charlie Price (UK). Nordic countries are also in the Management Committee of EU COST Action FA 1305 – Aquaponics HUB and EU LEO04027125 - EUROPEAN AQUAPONICS.

2. Facilities and studies performed by the partners

To fulfill each country requirements aimed for legislation and knowledge, three different system designs were set up, with trout-aquaponics in Norway and tilapia-aquaponics in Iceland. In Denmark, a tilapia/pike perch aquaponic system was designed, with ebb & flow techniques for mobile plant tables. The fish varieties were brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), Nile tilapia (*Oreochromis nilotica*), arctic char (*Salvelinus alpinus*) and silver perch (*Bidyanus bidyanus*). To find suitable plant species and varieties together with this fish wastewater, several plants were tried during the project period. The partners tested: salad rocket (*Eruca sativa*), mizuna (*Brassica rapa nipposinica*), dill (*Anthemum graveolus*), three different lettuce varieties (*Lactuca sativa* 'hjertesalat'/mini romano, crispy and lollo rosso), spinach (*Spinacia oleracea*), nasturtium (*Tropaeolum majus*), swiss chard (*Beta vulgaris*), pak choi (*Brassica campestris*), parsley (*Petroselinum crispum*), tomato (*Solanum lycopersicum*), basil (*Ocimum basilicum* Genovese, red and cinnamon-varieties), coriander (*Coriandrum sativum*), mint (*Mentha spicata*), watermelon (*Citrullus lanatus*), passion fruit (*Passiflora edulis*) and chili peppers (*Capsicum frutescens*).

Table 2.1-1:

Summary of design parameters of the aquaponic systems by the partners in the NOMA-project

Fish	Norway	Iceland	Denmark
Fish species	Rainbow/brown trout	Tilapia	Tilapia (Red and Silver), Pike perch
Total fish tank volume, m ³	2,4	0,3 m ³	6
Total fish tank area, m ²	8	1,0 m ²	9
Max fish size, kg	0,3	0,088	0,5; 0,9; 0,6
Max fish density, kg/m ³	17	31	75; 100; 40
Max fish biomass, kg	41	9,4	70
Max fish production, kg/year	360	6,8kg	280
Plants			
Plant species	Lettuce, etc.	Lettuce, etc.	Lettuce, Basil, etc.
Plant system	Deep water floating raft	Floating raft	Mobile plant tables, flood & ebb, soil pots
Total plant tank volume, m ³	6	0,6	None
Total plant tank area, m ²	20	2 m ²	30
Max plant biomass, kg	48	7,2	63
Max plant production, kg/year	416	6,6	441
Ratios			
Recirculation ratio	100%	80% 90% 100%	95-100%
g fish feed/day per m ² plant tank area	36,4	100	48
m ² plant tank area/ m ² fish tank area	2,5	2	none
Water treatment			
Swirl separators	Each fish tank, 17 l each	One each fish tank	none

Fish	Norway	Iceland	Denmark
Particle filter, m ³	Bead Filter, 0,4 m ³	Gravel filter	Pressure filter /biofilter 0,2 m ³
Sludge water handling	Aerob stabilization	Flushed out of system	none
pH-control	CaCO ₃	None	None so far
Biofilter, m ³	Moving bed, 0,25	Pumice, 0,3	See particle filter
Aeration/oxygenation/CO ₂ -stripping	Down-flow aerators, in- tank aeration	Airlift, in tank diffused aeration	Aerators in-tank low pressure diffuser (20l/min)
UV-irradiation	No	No	Not in use
Sedimentation, m ³	No	No	4
Temperature control	Heat pump	Geothermal water	Greenhouse central heating
Other supplements	Chloride	No	No
In-line measurements	pH, temp, O ₂ , flow	No in-line	pH, temp, O ₂ ,
Operation			
Flow, m ³ /h	~ 30	2,7	1
Total energy input		19,2 kwh	15 kwh/m ²
Man-hours per day	1	1	1/2

2.1. Facilities and studies performed in Iceland

2.1.1. Facility technical description

In order to investigate the relevance of constructing aquaponics production in relation to an already existing production of fish in Iceland, test facilities were designed in combination with an intensive production of Arctic char and Tilapia. Four distinct experiments were carried out:

- A flow-through experiment as compared with recirculation carried out in 2012 (Figure 2.1-1). The aim of this experiment was to investigate the potential of using the effluent from fish tanks directly for plant growth, as compared to without prior bio-filtration of the culture water from fish tanks using different approach (see Figure 2.2-1).
- Three consecutive experiments carried out in 2013-2014, for investigating the effects of 80% and 90% as compared with 100% recirculation of the culture water in fish tanks.

Study 2012

When planning the experimental setup, the criteria set was that the materials used had to be locally available and either cheap or reused. The trial should also represent a vision of a plant production model that could later be “scaled-up” to commercial size, and it had to provide useful, quantifiable data to scientifically address some of the questions that backyard aquaponics enthusiasts do not usually consider.

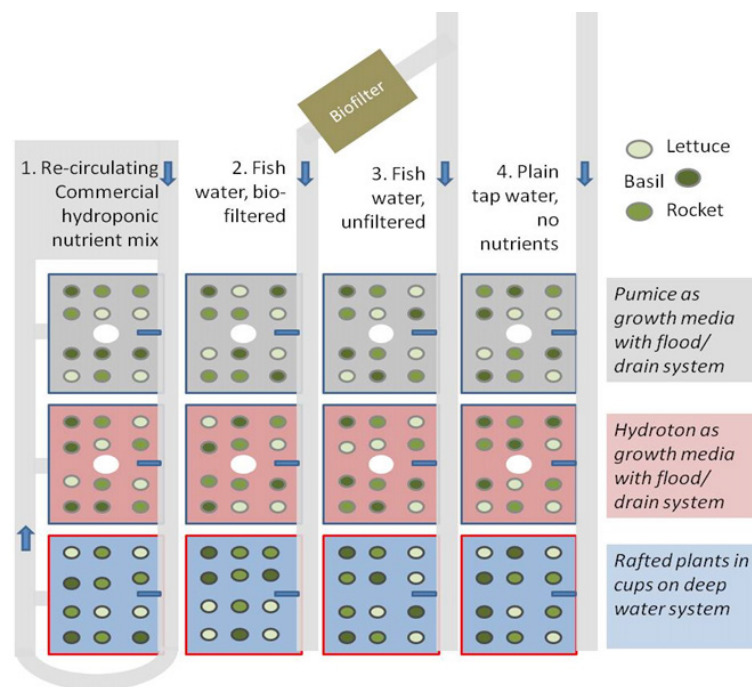


Figure 2.1-1.
Experimental design in the 2012 experiment.

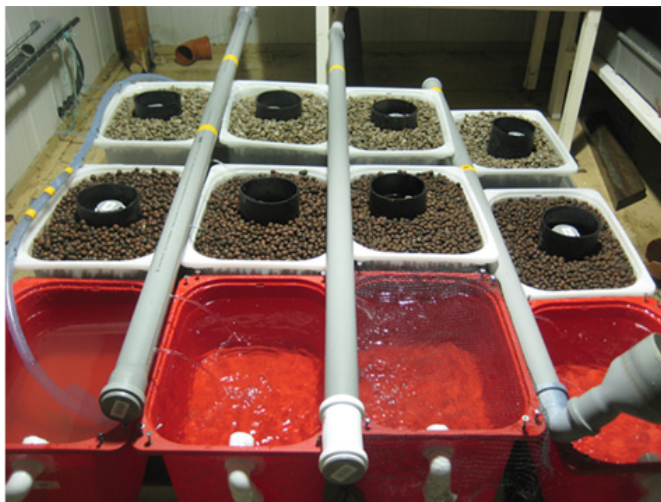


Figure 2.1-2:
The experiment boxes during set-up

The three different experiment boxes in each water treatment contained (table 2.1-1);

1. Pumice from nearby Hekla volcano, graded into 8-12 mm pieces.
2. Hydroton, a commercial media made of expanded clay pellets used for hydroponic plant cultivation.
3. Deep water or raft culture. Essentially just the water with the plants hanging above it so their roots were mostly submerged.

Three types of plants were chosen for the experiment, initially lettuce, basil and rocket (table 2.1-1). Four plants of each species were placed in each experiment box, giving 12 plants in each box, and providing some replicates in the event that not all the plants survived.

Table 2.1-1:

Experimental setup in 2012. The experiments were carried out in quadruple (x4).

Box	Labeling	Water Source	Grow system	Water system	Plants
1a	TP	Plain	Pumice	Flow through	Basilx4, Lettucex4, Rocketx4
1b	TH	Plain	Hydroton	Flow through	Basilx4, Lettucex4, Rocketx4
1c	TR	Plain	Rafted DWC	Flow through	Basilx4, Lettucex4, Rocketx4
2a	UP	Unfiltered	Pumice	Flow through	Basilx4, Lettucex4, Rocketx4
2b	UH	Unfiltered	Hydroton	Flow through	Basilx4, Lettucex4, Rocketx4
2c	UR	Unfiltered	Rafted DWC	Flow through	Basilx4, Lettucex4, Rocketx4
3a	BP	Bio-filtered	Pumice	Flow through; Bio-filtration	Basilx4, Lettucex4, Rocketx4
3b	BH	Bio-filtered	Hydroton	Flow through; Bio-filtration	Basilx4, Lettucex4, Rocketx4
3c	BR	Bio-filtered	Rafted DWC	Flow through; Bio-filtration	Basilx4, Lettucex4, Rocketx4
4a	NP	Nutrient mix	Pumice	Recirculating	Basilx4, Lettucex4, Rocketx4
4b	NH	Nutrient mix	Hydroton	Recirculating	Basilx4, Lettucex4, Rocketx4
4c	NR	Nutrient mix	Rafted DWC	Recirculating	Basilx4, Lettucex4, Rocketx4

Explanation – Latin names

Basil (ocimum)

Rocket (eruca)

Lettuce (lactuca)

The water in the experiment had four different sources. The plain tap water used was fresh water available on site, sourced from cold and hot underground sources on the farm. The unfiltered water from fish tanks was collected from the end of a raceway, a long rectangular concrete tank on Fellsmúli fish farm. Water in the raceway tank was a combination of water from several fish tanks, with a re-oxygenation step and fresh hot water added to raise the temperature. This combination of pre-used water, combined with the high density of adult tilapia living in the raceway, gave the (estimated) highest concentration of nutrients at the site. Water from the end of the raceway was pumped via a 100mm black heavy-duty flexible pipe around 100 m to the room where the experiment took place. The pumped water was sent into a settling tray, and then gravity fed into a perforated PVC pipe that sprayed at equal amounts into the three experiment boxes. Some of the same nutrient rich fish-waste water was directed into a pumice biofilter to amplify the plant-available NO₃-N in the water. The water from the biofilter was sprayed at equal rates into the three different types of experiment boxes. The recirculating water source was a nutrient-rich control of recirculating water that had carefully measured amounts of a commercial nutrient solution periodically mixed into it.

Study 2013-2014

Three experiments were carried out in the experimental setup. The trials were consecutively performed at different levels of recirculation: 80%, 90% and 100%, with a 4-week duration of each experiment. The main criteria when designing the experiment was that it could be scaled up to a commercial facility that could be viable for the average fish farmer. Furthermore, we took notice of the advantage of using the natural resources here in Iceland. This means that

the incoming water for the system was not filtered since it is pure spring water and geothermal water was used to obtain the desired temperature.

The recirculating system consisted of a culture tank from which water left through a center drain into a swirl separator. From there it overflowed into a pumice biofilter system. After leaving the biofilter system, the water was airlifted through pipes by means of two-step ladder system where the water was oxygenated and degassed. From the degassing tanks, the water flowed through a pair of clarifiers before entering a set of two hydroponic tanks from where it discharged into a sump. From the sump, water was pumped into a top tank from where it flowed by gravity back to the rearing tank. In this system, the degree of recirculation could be precisely determined by controlling the inflow of new water and outflow of nutrient-saturated water. A schematic diagram of the system is shown in figure 2.1-3.

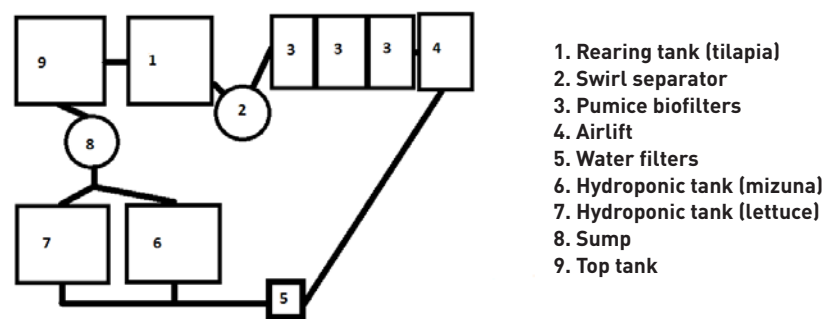


Figure 2.1-3.

Experimental design in the 2013-2014 experiment.

The system consisted of one culture tank (1 m³) for rearing of Nile tilapia (*Oreochromis nilotica*). Water level in the culture tank was kept at 0.40 cm to maintain the water volume at approximately 300 L. The tank opening was covered with a net to prevent the fish from jumping out of the tank. Figure 2.1-4 shows an overview of the fish tank, swirl separator, pumice biofilter, and the airlift. The biofilter system (figure 2.1-4) consisted of three chambers filled with varying amounts of volcanic pumice, which also served as mechanical filters. Water from the fish tanks flowed through the pumice medium, pulled by the force of gravity. Using air stones, the pumice medium was periodically oxygenated and purged of suspended solids. The large surface area of the pumice, regular oxygenation, and a steady supply of ammonia created favorable conditions for naturally occurring ammonium-oxidizing bacteria. Pumice is highly vesicular, mostly filled with air or water. When pumice is used as a biofilter it becomes saturated when the vesicles fill with organic matter and nutrient-rich water. Before the first trial started, the system was operated with fish for two months in order to acclimate and build up the biofilters. Prior to each of the three trials, approximately one third of the biofilter pumice was replaced with new pumice.



Figure 2.1-4:
Overview of the fish tank, swirl separator, and pumice biofilter. Photo: Matorka

2.1.2. Studies performed and goals

Three consecutive experiments were carried out in 2013-2014, for investigating, the effects of 80% and 90% as compared with 100% recirculation of culture water in fish tanks (see Figure 2.1-3). A flow-through experiment as compared with nutrient solution carried out in 2012, for investigating the potential for using the effluent directly for plant growth, as compared to without prior bio-filtration of the culture water from fish tanks using different approach (see Figure 2.2-1). Water samples were collected from the effluent water from fish tanks and plant growing beds at regular intervals throughout each experiment for measuring different water quality parameters as compared with the control units used in each experiment.

The water for the experiment (other than tap water) was drawn from the effluent from an outdoor Tilapia raceway. The pipeline from the raceway to the hall where the experiment took place was 75 m long. The temperature in the raceway was 23 - 25 °C but had cooled down to 20 – 21 °C by the time it reached the plant boxes.

The temperature, oxygen and pH was measured daily in the raceway. The raceway was 20m long, 3m wide and 2m deep or 120 m³. There were approximately 3500 kg of Tilapia in the raceway ranging from 50g – 200g in size. The fish were handled several times a day as well as from belt feeders. Three types of plants were chosen for the experiment, initially lettuce, basil and rocket (table 2.1-1).

Fish and plant growth were determined at the end of each experiment, for mass-balance calculations of the production capacity for each model. See detailed description in chapter 2.1.1 of the studies.

2.1.3. Procedures, instrumentation and analytical tools

Study 2012

Approximately 100 seeds of lettuce, basil and spinach were seeded in 20 mm inert coconut coir germination pads. Two seeds were seeded in each pad. After approximately a month, four individuals of each plant type were carefully separated from the other seedlings, washed of most of the coconut coir fibers and transplanted into each experiment box. Ten individuals

of each plant type were also treated in the same manner but collected for measurement and weighing to give the baseline data with which to compare the amount of plant growth at the end of the experiment.

The 12 individual plants, four each of lettuce, basil and rocket, were randomly arranged in each experiment box, with care taken to prevent the plant leaves being hit directly by the water flowing in to the boxes. For the pumice and Hydroton growing media, a small pit was made in the stones by hand, and the roots of each plant carefully covered. For the raft experiment boxes, the plants were placed in 35 mm diameter plastic baskets that were placed into holes cut in nylon netting. Photographs of each experiment box were taken each week to keep a record of plant health and growth.

The pH, temperature and dissolved oxygen (DO) of the water in the plant boxes were measured once a week. Each week, 500 ml samples from each experiment box, as well as some other system water samples, were collected in clean plastic bottles, cooled to ~4 °C and transported to Matis for analysis as soon as possible after sampling. Within 24 hours of sample collection, sub-samples of known volumes (usually 250 ml) were filtered with Whatman GF-C pre-weighed filter papers in a tap-fitted vacuum filter device. The filter papers were dried for 1-2 hours at 104 °C, until no more loss of mass was recorded, and then cooled in a desiccator and the dry mass of the suspended solids calculated as a gram per litre. This analysis resulted in the total suspended solids (TSS) information for each sample.

Fifteen milliliters of filtrate of each sample was collected in a plastic test tube and either frozen or analyzed immediately. Nutrient analysis was carried out on a FIALab 2500 spectrometer with an autosampler. At the end of the experiment, 10 individuals of each plant type were taken to Matis where they were arranged on white paper for measurement, photography and subsequent image analysis to determine leaf surface area. Parameters measured initially on each of the 30 plants were number of leaves, root length, stem length and total plant length. Five of each plant type were cut into roots, stems and leaves, weighed, dried for ~2 hours at 104°C, and then reweighed to determine the average pre-experiment fresh and dry weights.

The program Image was used to determine the leaf area of each plant.

Study 2013-2014

Twice per day, fish was fed floating extruded pellets, based on a special wheat- and rapeseed-based formula. The feed contained 30% protein, with minimal inclusion of fishmeal and oil (Fóðurblandan Reykjavík, Iceland) (tables 2.1-2 and 2.1-3). Fish were fed 200 g of feed daily, corresponding to the recommended feeding rate of at least 60-100 g of feed per one m² of hydroponic plant growing area (Rakocy et al. 2003). Amount of feed was kept constant throughout the study.

Table 2.1-2.

Macronutrient composition (%) of the fish feed. Information from feed producer (Fóðurblandan, Reykjavík, Iceland).

	% in feed
Protein	30
Fat	6
Carbohydrates	41
Fibre	6

Table 2.1-3.

Minerals and other dietary factors (mg/kg) in the fish feed. Information from feed producer (Fóður-blandan, Reykjavík, Iceland).

	mg/kg
Choline chloride	750
Magnesium	500
Zinc	120
Manganese	60
Copper	12
Iodine	7
Cobalt	5
Selenium	0.2

Water samples (200 ml) were collected three times per week, on Mondays, Wednesdays and Tuesdays. Samples were immediately frozen at -40°C. Water was sampled at two points in the system, from the fish tank and from the hydroponic tanks. Fresh water entering the system was also collected for comparison. Data were collected on fish growth and plant growth for each trial. Feeding data were also collected, including feeding rate and amount of feed. At the beginning and end of each trial, fish (10% of the population) were collected from the culture tank to estimate the average weight of fish in the tank. The fish were weighed using a calibrated scale, Valor 3000 Xtreme (Ohaus Corporation, New Jersey, USA), with an accuracy of 0.1 mg. Specific growth rate (SGR) was calculated using the following formula:

$$100 * ((\ln(\text{endpoint weight}) - \ln(\text{baseline weight})) / \text{days})$$

Thermal growth coefficient (TGC) describes fish growth independent of temperature and hence, corrects the effect of temperature on fish growth. TGC was calculated using the following formula:

$$100 * (((\text{endpoint weight}^{(1/3)}) - (\text{baseline weight}^{(1/3)})) / ((\text{number of days}) * (\text{water } ^\circ\text{C})))$$

Water samples were measured for total ammonia nitrogen (TAN) by semi-automated colorimetric at the Mátis Laboratories. Nitrite, nitrate, and orthophosphate were estimated from TAN by multiplying with the following conversion factors of 2.344, 11.5 and 1.377, respectively (Hamzasreef calculators).

Two hydroponic tanks were used for growing lettuce (*Lactuca sativa*) and mizuna (*Brassica rapa nipposinica*). The tanks were plastic, 30 cm deep, with a total surface area of 2 m². Plants were grown on floating sheets of 25 mm thick construction grade polystyrene. Circular holes (5 cm in diameter) were cut in the polystyrene where net pots for holding sprouting seedlings were placed. The spacing of the holes was 20 cm, from centre to centre. Roots were able to reach water through slits in the net pots, which were filled with clay pellets.

Seeds were planted into rock wool cubes where they were allowed to germinate and grow for two weeks in a separate system, using clean tap water, before being transplanted into the aquaponic system. A total of 23 lettuce plants and 23 mizuna plants were selected and transplanted into the aquaponic system. To minimize bias, plants were selected to be as similar in size as possible.

A single 600w Power plant metal halide light bulb was placed in a reflective hood at a suitable distance above the grow beds. The light source did not illuminate the whole growth bed equally, but the light was positioned in such a way that it would provide an equal amount of light for at least five plants of each species. Room temperature was kept constant at 20°C using an automatic hot air blower fan.

At the start and end of each trial, the height (mm) of five plants of each species was measured using a ruler. Length of leaves and stems was also measured. The five plants selected were the ones located in the brightest area of the hydroponic tanks, directly beneath the bulb. This was done to minimize potential bias due to the effects of variable light on growth. The measurements were repeated at the end of each trial. In addition, the plants were cut from the root and the yield (fresh weight of leaves and stems, and dry weight of roots) measured using a calibrated scale, Valor 3000 Xtreme (Ohaus Corporation, New Jersey, USA), with an accuracy of 0.1 mg.

Water temperature, dissolved oxygen, pH, and total dissolved solids were measured *in situ* on a daily basis. Water temperature and dissolved oxygen (mg/l (ppm)) was measured using OxyGuard Handy Polaris v. 3.03 EU (OxyGuard International A/S, Birkerød, Denmark). The pH was measured using pHep Tester (Hanna Instruments, Rhode Island, USA). TDS was measured using Eco Testr TDS Low (Eutech Instruments, Oaklon, Vernon Hills, Illinois, USA). All meters were calibrated prior to the start of the study.

2.2. Facilities and studies performed in Norway

A small aquaponics production unit was built at NIBIO Landvik (former *Bioforsk*). NIBIO has invested in and built a new greenhouse. NIBIO, NIVA, AqVisor AS and Feedback Aquaculture ANS have done the design of the production unit. All Norwegian partners have contributed in designing and building the unit.

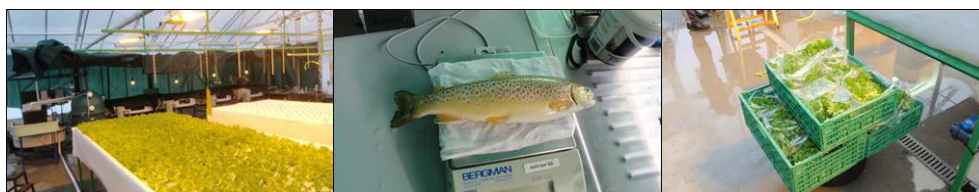


Figure 2.2-1:
The aquaponics pilot production unit at Bioforsk/NIBIO, Norway.

2.2.1. Technical description

The system built is a deep water culture (DWC) system modified after design described by Rakocy (2010). A flow chart of the system is shown in figure 2.2-2. A technical drawing of the system is shown in figure 2.2-3.

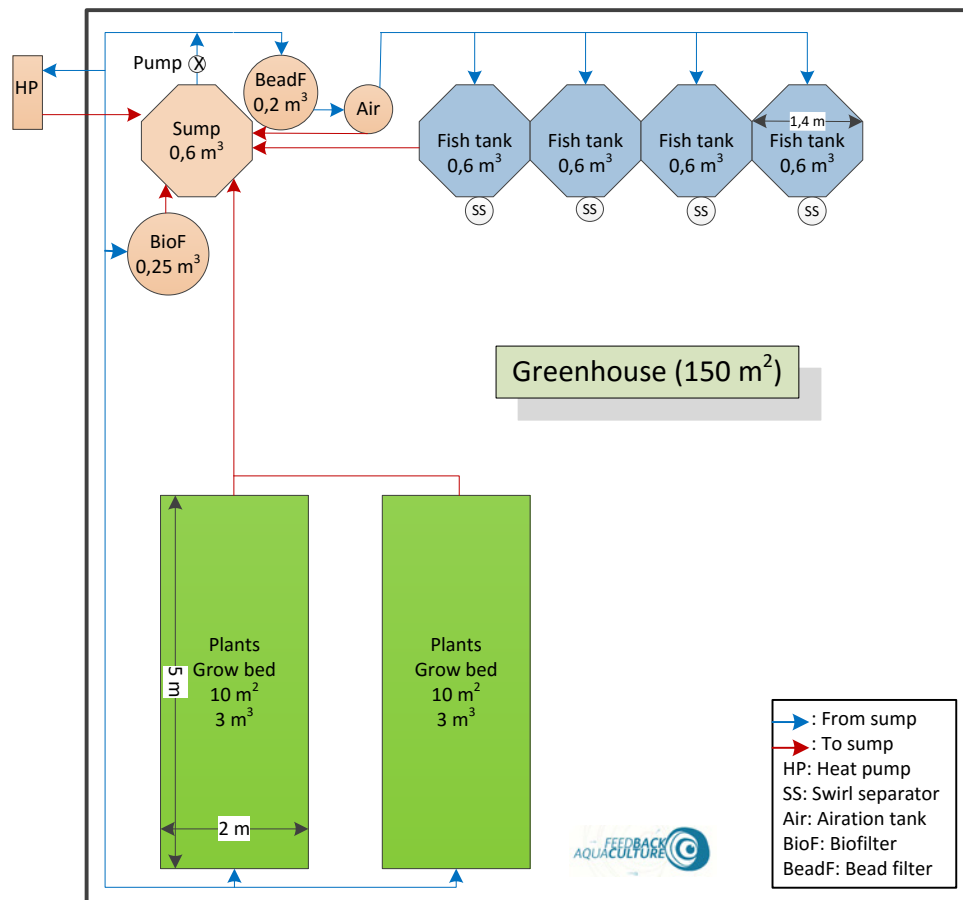


Figure 2.2-2:
Flow chart of aquaponics pilot system built in Norway

Total system volume, is 10 m³, consisting of two plant beds of 3 m³ each (6 m³), four fish tanks of 0,6 m³ each (2,4 m³), one sump of 0,6 m³, one aeration tank of 0,2 m³, beadfilter of 0,2 m³, biofilter of 0,25 m³, four swirl separators of 17 litres each (68 litres) and the rest of volume in system pipes. The biofilter is a MBBR (moving bed bioreactor) with K1 Kaldnes media. The bead filter is a Polygeyser DF-6 with enhanced nitrification (EN) bead media. Water is flowing by gravity to the sump, and the water delivers from the sump to all tanks by a water pump. Production and design parameters shown in table 2.1-1.

Particle filtration is done with the swirl separators and the bead filter. Fish tanks have dual drain for optimal particle separation. The system is designed as a zero discharge system with wet composting of the sludge. Water soluble nutrients from wet composting will be used in the aquaponics system. Further work on this will be done in future development.

Temperature control is done with heating of greenhouse and heating/cooling of water with a heat pump ($\pm 1^\circ\text{C}$). Oxygen and CO₂ are controlled by aeration in all tanks and a separate aeration tank. Air stones and bio-blocks are used for this.

Fish tanks are shaded with curtains with a total shade factor of 86% to reduce green algae growth in the nutrient wastewater from the fish in aquaponics.

Table 2.2-1:*Production and design parameters used for the aquaponics production unit.*

Parameter	Unit	Amount
SYSTEM		
Total water volume whole system	m ³	10
Number of fish tanks	#	4
Volume per fish tank	m ³	0,6
Total volume fish tanks	m ³	2,4
FISH		
Weight fish start	kg per fish	0,1
Total number of fish produced	per year	1200
Biomass of juveniles	kg per year	120
Weight of fish at harvest	kg per fish	0,3
Biomass at harvest	kg per year	360
Total biomass produced	kg per year	240
Max standing stock	kg	41
Number of fish per tank	#	50
Average standing stock	kg	33
Average standing stock per m ³	kg/m ³	13,75
Biomass per tank (max)	kg	15
Biomass per m ³ (max)	kg/m ³	25
Water exchange per tank (max) ¹⁾	l/min	22,5
GROWTH		
Specific growth rate (SGR)	% per day	2
Feed conversion rate (FCR)	kg feed per kg weight gain	1
Average daily feed demand	kg per day	0,66
Total feed demand	kg per year	240
Total production TAN ²⁾	kg per year	8,9
Production time ³⁾	days	55
PLANTS		
Average size at harvest (salad)	gram	100
Numbers per m ²	#	40
Production cycle (total)	weeks	7-8
Time in nursery system	weeks	3
Time in aquaponic production system	weeks	6

¹⁾ ΔO₂ = 2 mg/l, O₂ consump. = 3 mg/kg BW²⁾ 42% protein in feed³⁾ from 100g to 300g

Datalogging

In addition to all manual sampling, the aquaponics installations at Bioforsk Landvik were equipped with automatic monitoring systems for pH, temperature, oxygen, system flow through, and signal-controlled dosing pump for additional buffer-solution (CaCO₃ powder as slurry). Two groups of pH-, temperature- and oxygen sensors were placed in strategic places. One at the sump where all the water is mixed before being recycled back to plants and fish, and the other where water returns from the fish tanks. The pH measured in the sump was converted to a process signal used for CaCO₃ dosing and logged in a separate datalogger. The flowsensor was placed at the outlet off the sump. In addition to these parameters, the total power supply to the aquaponics system was monitored. 8 parameters were logged by an analog AAC 3100 datalogger equipped with a Siemens GSM-modem for communication with an external host at NIVA. The system was powered by UPS 24 VDC (fig 2.2-4).

pH measurements

Each set consisted of a pH-element (Hamilton Polilyte Plus 120) which was connected to a Knick Pikos signal converter converting the high impedans mV signal to a robust mA signal using power from a 24 VDC source. This primary circuit was transmitted to a secondary adjustable loop powered circuit created from an M-System M2XU Universal Transmitter. The secondary circuit was converted to pH, logged and displayed by the logger. This system made it possible to use both a two point calibration (buffer 4 and 7) and to process calibrate (actual known value set to the logger).

Oxygen and temperature

Two Sentronic SentrOxy WQM-sensors for oxygen and temperature measurements were supplied by galvanic separate 12 VDC converters. Primary current circuits were transmitted to secondary circuits by M-System M2XU Universal Transmitters and values stored in the AAC-logger.

Flow

A Grundfos VFI (0,3-25 m³/h) flowmeter powered by a 24 VDC source delivered a 4-20 mA signal to the datalogger.

Dosing-signal

A mA signal from control unit in lime-slurry pump system was monitored and stored in the logger.

Power supply guard

A net adapter 240 VAC/5 VDC delivered volt signal to the last logger channel when net power was available. A schematic presentation of the sensors, logger, communication equipment and power supply is given in figure 2.2-4. After a period, the O₂ and temperature-sensors for return water from the fish tanks were placed in fish tank no 1.

Alarms

The AAC-logger was equipped with 4 relays, each capable of sending an alarm from 4 freely selectable canals. The alarm was sounded by ringing a special alarm telephone (mobile SIM card). If the first guard did not answer, automatic handoff was given to a second telephone number as guard 2. This option was delivered by the telephone company. Parameters, channels, span and alarm settings are displayed inn table 2.2-2.

Table 2.2-2:

Parameters, measuring borders and alarm triggering points in logger setup at NOMA aquaponics Landvik.

Parameter	Unit	Span	Alarms
pH water from fishpan	pH	4-14	
Temepature fish pan	°C	0-100	
Temperature collecting pan	°C	0-100	
Oxygen fish pan	mg /l	0-20	<6
Oxygen collecting pan	mg /l	0-20	
Water flow	l/min	0-667	<60
Limb dosing signal	ml/min	0-330	
Power supply	VAC	0-240	<160

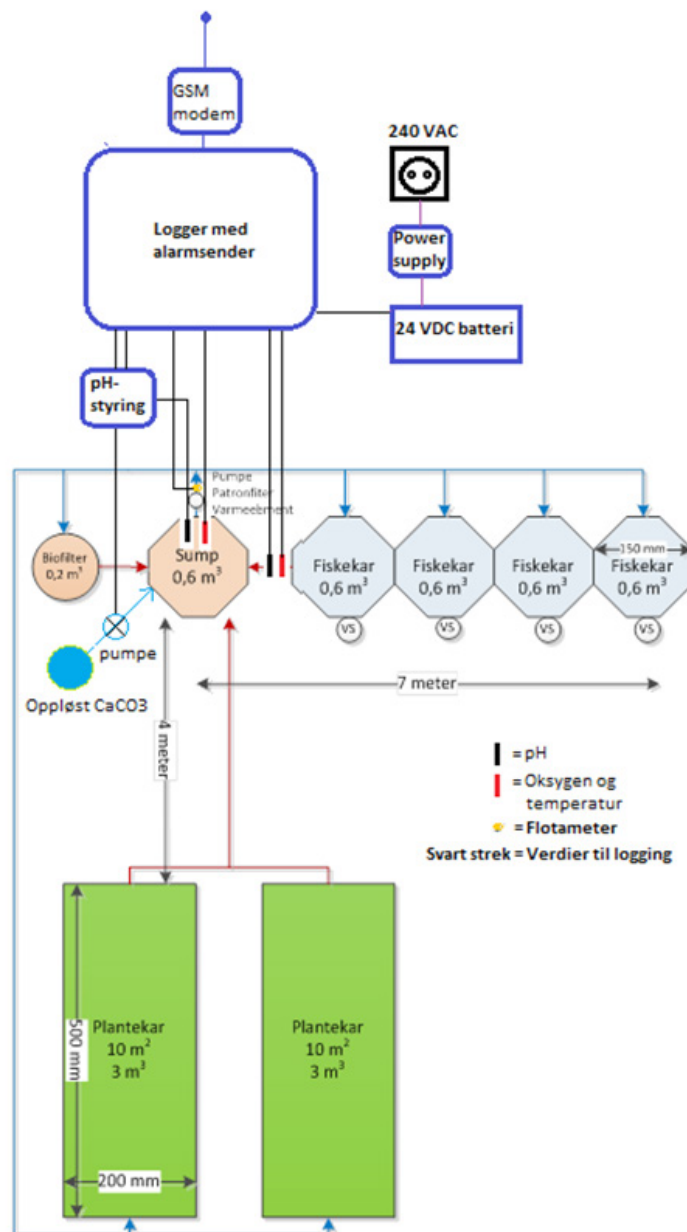


Figure 2.2-4:

Schematic presentation of sensors, logger, communication equipment and power supply.

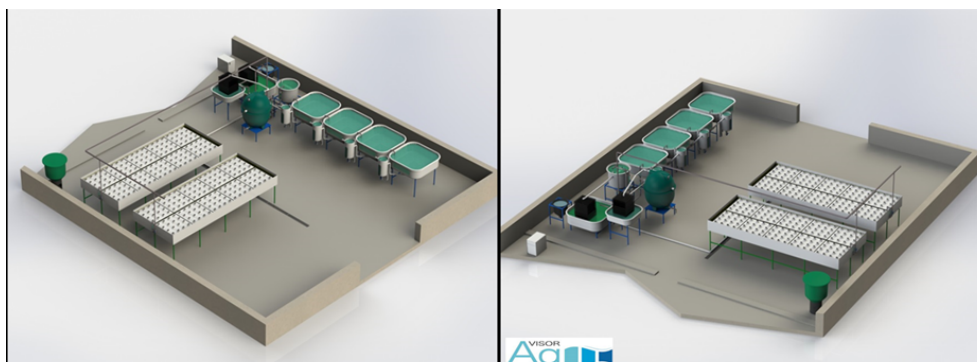


Figure 2.2-3:
Technical drawing of aquaponics pilot system built in Norway

pH control system

In order to counteract harmful pH decline, CaCO_3 was added to increase pH in the circulating water. During most of 2014, limestone powder was manually added to obtain pH control. By November 2014, automatic lime slurry dosing was implemented. A bucket was filled with water and lime powder to make slurry. Compressed air was used to keep the CaCO_3 in suspension. Lime slurry was added using a Watson-Marlow 313 peristaltic pump. The dosing principle was based on PI regulation principle with pH value as set point. In addition to components described above (pH measurements), the system consisted of a PR electronics 2289 signal converter and a INTAB Tinytag mA single channel logger with display. Using a 48 mm pumping hose, theoretical dosing capacity was maximum 330 ml/min.

Plant studies

Two plant beds for deep water culture were built, each of 10 m². In the spring 2014, one was filled with aquaponics solution connected to fish tanks, and the other one was filled with hydroponic water (standard nutrient solution Calcinitt and Superba, 1700 $\mu\text{S}/\text{cm}$). Both plant beds were used for growing different crops: different varieties of lettuce (*Lactuca sativa*), mizuna (*Brassica rapa nipposinica*), parsley (*Petroselinum crispum*), dill (*Anethum graveolens*), different varieties of tomato (*Solanum lycopersicum*), nasturtium (*Tropaeolum majus*), swiss chard (*Beta vulgaris*), pak choi (*Brassica campestris*). The tanks were built up from steel and wood with a pond cover in plastic, water deep about 30 cm, with a total surface area of 20 m². Plants were grown on floating boards from the company Dry Hydroponics in polystyrene, in two different sizes, one for 12 plants and one for 24 plants. Seeds were planted into rock wool cubes where they were allowed to germinate and grow for three weeks in a separate nursing system, using aquaponics water, before being transplanted into the aquaponics tank. Fourteen boards were placed in each plant tank of 10 m².



Figure 2.2-5:
Plant nursery in Rockwool cubes, put out in the system after three weeks. Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO

Bioforsk conducted four plant experiments to document plant growth in a trout aquaponics during 2014 and 2015 to provide information for plant selection and crop choice for an economic viable food production for Nordic aquaponics. The studies included selection of suitable plants, comparing young and elder plants in the system with respect to pathogens, diseases and nutrient deficiency.

Plant growth was measured in a growing period of eight weeks in the 2015 experiment. Around 21 days after sowing, the plants were transferred to the aquaponics floating system, using floating trays with a plant density of 40 plants per square-meter. Maximum root length and plant diameter, were observed between day number 28 and 42 (figure 3.2-10). Plants were weighted as single plants by a nondestructive method: splitting the Rockwool block carefully at one side and take out the plant with roots for weighing before replacing it into the system for further growth. Four representative plants were selected from each floating board of 24 plants each (figure 2.2-5).

There were four replicates of boards (4*24=96 plants) per growing stadium. In the first experimental plot (trial 1, 2014), there was three varieties (figure 3.2-3), and 48 plants per treatment, half were aquaponics and the other half hydroponics, all together 96 plants.

Another plant study (trial 2, 2014) was performed to study how elder plants were growing in fish effluent water. The plants were observed for nutrient deficiency symptoms at the start of the experiment and weekly during six weeks. In trial 2, the plants were nursed in hydroponics water, and moved to aquaponics water on 11th of April 2014. The temperature was around 15° C, both in water and air. Results of water analysis is presented in table 3.2-3. The species tested here were dill (*Anthemum graveolus*), three different lettuce varieties ('hjertesalat'/ mini romano, crispy and lollo rosso), parsley (*Petroselinum crispum*) and tomato (figure 3.2-6). All plants were grown in floating bed system.

A third trial (trial 3, 2014) was performed with a lettuce variety 'Hilde'. A last trial (trial 4, 2015) was conducted to see how plants (lettuce variety 'Crispi') performed using exclusively aquaponics water from nursery stage to product, and at the same time calculate biomass balances. The test area was 20 m² and had 28 floating boards with plants, each containing 24 plants during the 4 weeks the plants were in the system (figure 3.2-16, table 3.2.6).



Figure 2.2-6:

Weighting plants (lettuce 'Crispi') without the Rockwool cube. Photo: Siv Lene Gangenes Skar, Bioforsk.

2.2.2. Studies performed and goals

To be able to do the necessary studies it has been built a new green house with an aquaponics system designed for this study. The studies performed is

1. Water quality guidelines and documentation of fish growth
2. Plant species in aquaponics and documentation of growth and environmental parameters.
3. Mass-balance calculations, implementation of water treatment technology and testing of the pilot-scale systems to produce water with optimal water quality for both plants and fish.
4. Design of a commercial production model with modelled contribution margins.

Results from the studies:

1. Water quality parameters according to regulations for aquaculture and animal welfare must be maintained. Trials have documented growth of fish in aquaponics systems.
2. Performed experiments have documented plant growth in aquaponics systems.
3. Performed experiments have documented the system. Mass-balance calculations for the production capacity of the systems have been performed.
4. Commercial production design with modelled contribution margins has been performed.

2.2.3. Procedures, instrumentation and analytical tools

For control and monitoring, both continuous in-line measurements and manual sampling and analysis were applied. The in-line monitoring, control and alarm system is an integrated part of the aquaponic system and described in chapter 2.2.1. During ordinary operation, basic water quality parameters, including total ammonia (TAN), nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), phosphorus, conductivity and turbidity were measured twice a week. In addition, representative samples of fish and plants were taken out to control weight and size on a regular basis. The daily fish feed consumption was monitored.

For making a mass-balance on nitrogen and phosphorus over the system, determine the water quality development over time, and estimate the production of the system in terms of fish and plant biomass, a two month intensive sampling campaign was conducted, from 16.01.2015 to 13.03.2015. All inputs (food and water) and outputs (fish- and plant biomass and sludge) and accumulation in the system were monitored. Additional samples were collected and additional water quality parameters were included. The water quality parameters are shown in table 2.2-3. The volume of the backwash-water from the bead-filter and the sludge from the swirl separators were measured daily, and analysed for suspended solid, tot-N and tot-P. Samples were analysed at Norwegian Institute for Water Research (NIVA) according to accredited standards. Metals were analysed using inductively coupled plasma atomic emission spectroscopy (ICP/AES).

Table 2.2-3:

Additional water quality parameters analysed during the sampling campaign period from 16.01.2015 to 13.03.2015

Parameter and units	Analytical method
Potassium	Ion chromatography
Calcium	Ion chromatography
Magnesium	Ion chromatography
Sodium	Ion chromatography
Aluminium	ICP/AES
Boron	ICP/AES
Iron	ICP/AES
Copper	ICP/AES
Manganese	ICP/AES
Molybdenum	ICP/AES
Silicon	ICP/AES
Zinc	ICP/AES
Sulfur	ICP/AES
Total phosphorus (Tot-P)	Autoanalyzer
Total nitrogen (Tot-N)	Autoanalyzer
Total Organic Carbon (TOC)	UV-oxidation, NS-ISO 8245

Additional experiments were conducted to measure the particle separation efficiency of the beadfilter. 24-hours composite samples were collected from influent and effluent on 4 different days. Also experiments to concentrate aerobic stabilized sludge were performed. Natural biopolymers (chitosans) were used for coagulation and precipitation of the solids. The nutrient rich clear-phase was recycled back to the system, while the remaining concentrated sludge will be treated for use as fertilizer and/or soil improvement.

2.3. Facilities and studies performed in Denmark

2.3.1. Technical description of facility

The IGFF test plant in Denmark was set up in the autumn of 2014 in an existing greenhouse research facility build autumn 2013 and owned and run respectively by Copenhagen University and the public-private innovation center for horticulture: AgroTech Ltd. The greenhouse itself is divided into 12 'cubes' of each 50 m², and so has the prospect of making individual research in the large greenhouse itself. Each cube has a 24-hour data logging on temperature inside and outside, climate control on light, humidity, ventilation and heat. The aquaponic test plant is placed in one of the cubes, and uses excess space of 15m² outside the cube for the placement of bio-filter, sedimentation tanks, air-blowers and UV-system to secure as much plant growing area as possible.

The aquaponics test plant inside the cube consists of six plant tables arranged in three pairs of 1.45 x 7.50 m and are covering three rectangular fish tanks (3 x 1 x 0.8 m) with a usable volume of two m³ each. Plant tables produce horticulture products in pots with compost to open up for the prospect of getting an organic certification for the aquaponics system. To obtain an organic certification it requires that plants growths in various specified types of soil.



Figure 2.3-1:
Mobile plant tables placed above the rectangular fish tanks

The water supply to the plants is by the ‘flood and ebb’ principle. To secure as much plant growing area in the cube, bio-filter, UV-lighting, air pumps, pH regulation and sedimentation tanks are placed outside the cube. The oxygen supply to the fish tanks are secured by three independent air blowers. The tanks connects to a central water discharge line that ends in two sedimentation chambers. These chambers do not only serve as pre-filtration system but also as pump sumps. Each chamber is connected to one separate lift pump providing a pumping capacity of around 15m³/h. The total water flow is split into two, basically independent loops. In one of them, the fish loop, the pumps are supplying water to a bead-filter that acts as a mechanical- as well as a biological filter and one in-line ultraviolet disinfection system (UV-system) connected in series. From the UV-system, the water can be lead to the plant tables and/ or directly back to the fish tanks located beneath the plant tables. The water from the plant tables can also enter the fish tanks by gravity or can be directly discharged into the main discharge line and the sedimentation chambers. In the second loop (plant loop) the lift pump supplies the water directly back to the plant tables from where it will enter the fish tanks. Both lift pumps are frequency regulated, furthermore the plant loop pump is equipped with a timer that allows to pre-set pumping time and -duration to follow a “flood & ebb” watering schedule of the plant tables.

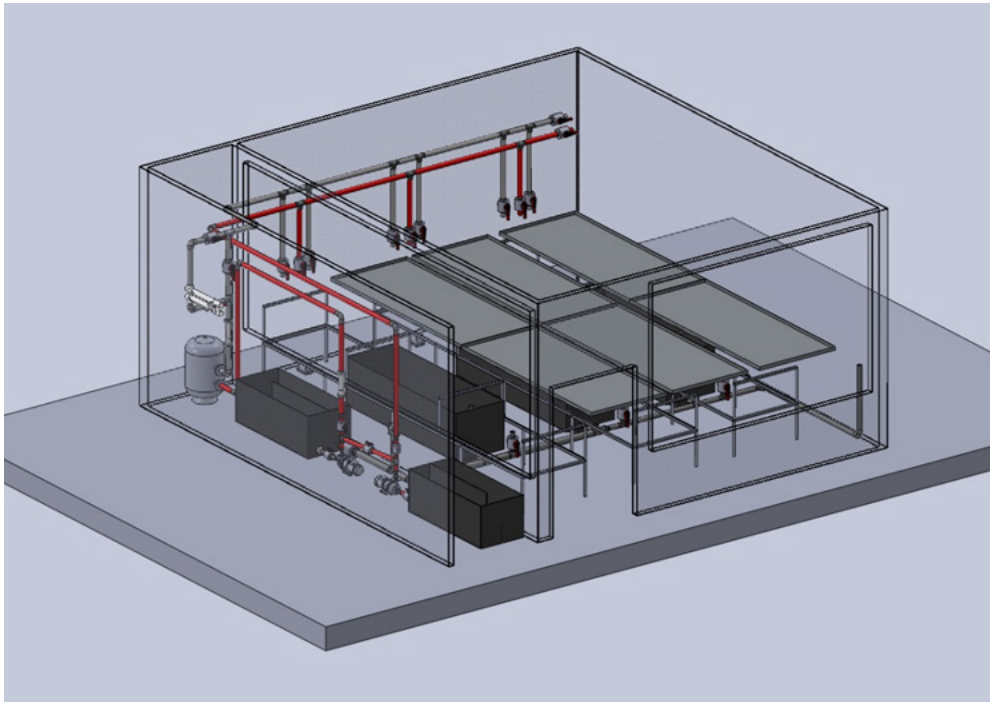


Figure 2.3-2:
A principle sketch of the IGFF aquaponics system.

Introducing two separate loops, one for plants and one for fish, gives a very high degree of flexibility and safety of production. The system allows the gradual reduction of the independence of the loops up to a system solely depending on the mutual symbiotic relationship of plant- and fish production. If at any time there is an imbalance of the two components, it is possible to (partly) separate the processes and stabilize the system again.



Figure 2.3-3:
Bio-filter, UV-lighting, sedimentation tanks and airblower. Photo: Paul Rye Kledal, IGFF.

2.3.2. Studies performed and goals

Studies have been done to measure the symbiotic effects of aquaponics, and so contribute to the economic analysis of the Aquaponics NOMA project.

Studies related to the fish:plant biomass ratio and sustainable harvest strategies of the IGFF system, are yet to commence due to the late installation of the IGFF production system. However, once production has reach a steady state in a peak fish biomass, scientific analysis and measurements on biomass ratios will take place. The study referring to on biomass ratio between fish and plants is not part of the obligations for IGFF (hence the NOMA project), but regarded necessary to be undertaken for estimating the productivity of the IGFF aquaponic system itself.

In the beginning of October 2014, 275 Red Tilapia and 275 Silver Tilapia fingerlings between 0.2-0.5 g were introduced to two of the three fish tanks. In the beginning of January 2015, 175 Pike perch of 25 g were introduced to the third and last fish tank.



Figure 2.3-4:
Weighing Red Tilapia fingerlings for optimum feed calculation

While the fish biomass is growing, various horticultural plants have been tested successively. Since the IGFF aquaponics system applies nutrient based compost to the plants, short time cultures (4-5 weeks) such as herbs like Basil Genovese have shown a healthy growth when starting up the system. However, longer-term cultures like salad and further time-consuming cultures like tomatoes and peppers have shown potassium deficit after 8 weeks. There has been no pH regulation so far due to a very high pH 8.1 in the water, but one could consider adding potassium hydroxide for later testing on longer-term cultures such as tomatoes.



Figure 2.3-5:
Testing a variety of horticultural products such as coriander red basil, basil Genovese, parsley, mint, watermelon, passion fruit and chili peppers on the table in the back of the picture.

2.3.3. Procedures, instrumentation and analytical tools:

The symbiotic effect of aquaponics

Year round simulation were performed with the core of The Virtual Greenhouse™ of AgroTech (www.dvv.infogrow.dk) (Körner and Hanssen, 2012) that consists of a compilation

of physical and biological greenhouse simulation models. In connection to this an aquaponic system model was created consisting of a 1000 m² Venlo-type greenhouse and growing area (4 m gutter heights, 2x25x20m area) volume of 65 m³ water capacity separated in 6 circular tanks of each 10 m³ plus system components as pipes etc. of 5 m³ water. The rectangular fish tanks were placed under the mobile plant tables.

The aquaponics system (AkvaGroup, Denmark) was dimensioned to produce 9 Mt tilapia fish yearly. For that a peak system biomass of 3000 kg fish was calculated. The fish feed was given to the optimum with a peak feed capacity of 40 kg day⁻¹ and a peak water exchange of 0.58 m³ h⁻¹ and minimum intake capacity of fresh water was calculated from transpiration and evaporation losses. Additionally, the needed water supply for keeping the desired water temperature at minimum of 28°C, and a maximum of 32°C was calculated from fresh water supply at pre-heated water. Energy supply to the water system was calculated by heat production through the fish calculated from an average oxygen consumption rate of 0.54 kg kg⁻¹ feed with 13608 J g⁻¹ feed. A rate of 51% of oxygen waste was assumed. Additional heat production was calculated by biological break-down of feces (1.3 MJ kg⁻¹ feed) and feed. Feed composition was 38% protein, 10% fat and 20% carbohydrates. The rates of energy conversion was 23.64 J g⁻¹, 39.54 J g⁻¹ and 17.15 J g⁻¹ for protein, fat and carbohydrates, respectively.

The greenhouse was a standard greenhouse type with lettuce cultivation. The greenhouse was equipped with an energy screen (LS16, Ludvig Svensson, Sweden) and a shading screen (ILS60 Revolux, Ludvig Svensson, Sweden) under the roof and equipped with standard heating pipe system and passive roof vents. Climate control was done according to common practice with installed supplementary lighting of 80 Wm⁻² (HPSL 400 W, Philips, The Netherlands) and sufficient dosage capacity of pure CO₂. However, temperature set-points for lettuce cultivation were set to 18 and 22°C year round. No distinguish between seasons, day and night and cultivation stage was done for model simplification. CO₂ was dosed to a maximum of 1000 ppm at daytime, but supply stopped when vents were opened with more than 10%.

For simulations, the Danish reference climate year (Lund, 1995) with hourly data was used as input. Simulations were done with a 5-min time step over a complete year. Two cases were simulated: 1) The greenhouse without aquaponics system using regular lettuce cultivation on benches (same climate set points as with aquaponics) and 2) the greenhouse with the combined 6-tank aquaponics system installed under the benches.

There is a trend now showing that greenhouses with aquaponics system installed, achieves higher crop yield and additional CO₂ supply for the greenhouse is strongly reduced. Also the total energy consumption for greenhouse heating is less.

In addition, CO₂ supply for elevated CO₂ level could be reduced strongly by the supply from aquaculture. A regular dosage of 2.89 kg m⁻² year⁻¹ was needed, while this could be reduced to 0.35 kg m⁻² year⁻¹. In addition, due to the higher CO₂ level in the case with aquaponics (since active CO₂ supply stopped with vent opening at >10%), a fresh yield increase from 43 to 49 kg m⁻² was achieved, i.e. a 14% yield increase. Assuming an average lettuce target head weight of 250 g, 24 more heads per m² greenhouse were produced each year (i.e. 24000 more heads in total for the 1000 m² greenhouse). However, lettuce development time was not taken into account here, and a higher individual head yield would be another possibility.

The comparing simulations show that heating for greenhouse could be reduced from 1.0798 GJ m⁻² by 21% or 0.22 GJ m⁻² year⁻¹ to 0.8569 GJ m⁻². In total, the aquaponics system could save 223 GJ heat energy. Both cases used electricity for lamplight consumption of 0.637 GJ m⁻².

3. Results from performed investigations

3.1. Results from WP1 studies: Fish

Three experiments were carried out on fish in the different aquaponics systems designed by the project, two at an existing aquaculture farm in Iceland and one in new aquaponics facilities designed and built in Larvik in Norway. In Denmark the aquaponics production started in the autumn of 2014 so presently data on fish growth rate, feed level and nutrient content is measured together with various water quality parameters for later carrying out biomass ratio analysis in comparison to plant output.

3.1.1. Summary of report on effluents and growth

Iceland

The two distinct experiments carried out in Iceland included a study on the growth of three selected plants in the effluent water from the production of Tilapia and Arctic charr in 2012 (no recirculation) and three consecutive experiments studying the growth of two selected plant species with 80%, 90% and 100% recirculation of the culture water of Tilapia. The experiment carried out in 2012 also included a comparison of flow-through tap water, biofiltered water, unfiltered water and a recirculating hydroponic nutrient solution for plant growth, each in three different media, pumice, hydroton and hydroponic raft medium.

Main results from the Icelandic studies indicate higher growth of tilapia at lower (80%) as compared with high (90% and 100%) recirculation level (Table 3.1). However, the lower biomass obtained at higher recirculation level is expected to be related to lower temperature that will cause environmental stress on the fish. This difference in temperatures is explained by reduced influx of warm water into the system with increasing recirculation levels, and is taken into account when calculating the thermal growth coefficient (table 3.1-1).

Analysis of the water quality showed that all the parameters measured fluctuated throughout the experimental periods, emphasizing the importance of monitoring the quality of water to the fish tanks as well as to the plant units. Whereas the optimal water temperature for most hydroponic plants is around 24°C, while the fish produced may have much lower optimal temperatures for growth, a high level of water recirculation requires a specific system for controlling the temperature in the fish and plant tanks of the system.

Experiment 1 was aimed at investigating the growth of different plant species in a flow-through effluent water from fish tanks, while Experiment 2 was aimed at investigating if different degree of recirculation of the effluent water from fish tanks would affect the growth of selected plant species. Hence, no comparison to no recirculation of the effluent water from fish tanks was included in Experiment 2.

Table 3.1-1:

Average biomass and changes in biomass during the course of the study at different levels of recirculation.

Level of recirculation	80%	90%	100%
Initial biomass (g)	2617	6075	2496
Biomass on day 30 (g)	9427	9874	5889
Difference (g)	6810	3799	3393
Increase (%)	182	38	136
Specific growth rate (SGR)	4.3	1.6	2.9
Thermal growth coefficient (TGC)	1.0	0.5	0.7

It is highly unfortunate that the original biomass of fish was higher in the 90% trial as compared to the 80% and 100% trials. This is explained by the equal number of fish put in the tanks in all three trials, which were then carried out in a consequent manner. The 80% trial was carried out first and when the fish was quite small and of quite variable sizes (fish not size graded). The 90% trial was carried out next and on larger fish, which makes the size effects more prominent (fish not size graded). However, in the 100 % trial, the fish had been size-graded and the smaller size group used in the trial, which reduces the initial biomass as compared with the 90% trial.

An appropriate density of fish was used in all three trials.

Norway

In Norway, experiments have been performed with use of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Rainbow trout was supplied by Lerøy AS, and brown trout was delivered by Syrtveit Fiskeanlegg AS. Rainbow trout is selected and bred for cultivation. The spawning stock of brown trout is wild caught and juveniles are used to strengthen wild stocks.

A summary for the system used, is shown in table 3.1-2. The experiments were performed in an aquaponics system with combined production of plants and fish. The system is 100% recirculated. Oxygenation of the system was performed by air stones in all tanks.

Table 3.1-2:

The system used during experiment (see also technical description 2.4.1).

System	Unit	
Fish tanks	numbers	4
Fish tank volume	m ³	0,6
Aquaponic system	100 %	recirculation
Total system volume	m ³	10

In table 3.1-3 is shown the water quality parameters during the experiments. Results are shown as average values with the standard deviation (SD). Temperature is kept by heating/aerate the greenhouse and by heating/cooling the water with a heat pump. The pH of the system has automatic logging and is adjusted with the use of CaCO₃. Chloride was added by the addition of CaCl₂. This was done to stabilize the system. Prior to this we had some mortality in the system with indications of nitrite toxification. After the addition of chloride, there was no mortality in the system.

Table 3.1-3:*Water quality parameters in the experiment (see also 3.3 Technology)*

Parameter	Unit	Value
Temperature (± SD)	°C	16,3 (± 0,5)
O ₂ , supply to fish tanks	%	100
pH (± SD)		6,9 (± 0,1)
TAN (± SD)	mg/l	0,1 (± 0,02)
NO ₂ -N (± SD)	mg/l	0,18 (± 0,03)
NO ₃ -N (± SD)	mg/l	100 (± 30)
PO ₄ ⁻ (± SD)	mg/l	3,6 (± 0,7)
Cl ⁻ (± SD)	mg/l	100 (± 11,6)

Table 3.1-4:*Production parameters from the experiment (see also 3.3.1)*

Parameter	Unit	Rainbow trout	Brown trout
Period	Date	30.01-13.03 2015	30.01-13.03 2015
Fish tanks	numbers	2	2
Fish at start	numbers	100	100
Fish at end	Numbers	40	80
Start weight (wet weight) (± SD)	g	291(± 50)	129 (± 29)
End weight (wet weight) (± SD)	g	583 (± 106)	155 (± 27)
Growth (daily growth rate) (SGR)	%	1,7	0,5
Mortality	#	0	0
Fish produced	g	12896	2235
Feed used	g	19100	5390
Feed conversion rate (FCR)	ratio	1,5	2,4

In table 3.1-4 is shown the comparative production results of rainbow trout and brown trout in the experiment. The experiments were done in parallel in the same system. The only difference is the species. From the results we can see that rainbow trout has a higher growth rate than brown trout. The brown trout used is 1st generation of wild caught fish, while the rainbow trout is used for cultivation and is selected for this. However, both species performed well in the system, and no mortality was observed.

Table 3.1-5:*Recommended water quality for salmonids.*

Parameter	Unit	Driftsforskriften ¹⁾	VKM ²⁾
O ₂ saturation	%	80-120	85-140
O ₂ in water	%	>90	<140
O ₂ out water	%	>80	>85
Total gas saturation	%		<110
Temperature	°C		6-20
pH	log ₁₀	6,2-6,8	>6
CO ₂	mg/l	<15	10-20
Alkalinity	mg/l CaCO ₃		50-300
TAN (NH ₃ +NH ₄)-N	mg/l	<2	
Ammonia (NH ₃ -N)	mg/l		0,012-0,025
Ammonium (NH ₄ -N)	mg/l		
Nitrite (NO ₂ -N)	mg/l	<0,1	<0,1
Nitrate (NO ₃ -N)	mg/l		150-400

¹⁾ Recommendations given in Norwegian aquaculture regulations.²⁾ Recommendations given in a new report on recirculated aquaculture from «Norwegian Science Comity for Food Production (VKM).

We found that the water quality parameters measured during our experiments were well within recommended values for good water quality for salmonids. The only exception was nitrite values. This caused some problems of fish mortality. We will recommend the addition of CaCl up to a level of 100 mg/l of Cl⁻.

Denmark.

Two important start up lessons from the Danish fish trials, which are still in progress to reach a steady state and secure a dynamic harvest strategy preparing for valuable biomass ratio analysis in this regard.

The first lesson is that inserting small fingerlings (0.3 gram) in a tank size prepared for end harvest level is not suitable. Growth rate has been slow, and seems to point at the problem of finding the feed. Secondly, problems of keeping the water temperature above 20°C has also been difficult at times during winter despite 23°C is set for the air temperature in the greenhouse. Solution: The fish tanks will have small heating pipes installed at the bottom controlled by thermostats to secure a better and stable growth rate.

3.1.2. Summary of report on comparison of results.

The system applied in Norway is 100% recirculated. In the experiments, we compared the growth of rainbow trout and brown trout. Rainbow trout had far better growth than brown trout. Both species performed well with no mortality. Price for product will decide what specie to use.

In Iceland, three consecutive experiments were carried out for studying the growth of two selected plant species with 80%, 90% and 100% recirculation of the culture water of Tilapia. The main results indicate higher growth of tilapia at lower (80%) as compared with high (90% and 100%) recirculation level. However, the lower biomass obtained at higher recirculation level may be the result of lower temperature that will cause environmental stress on the fish and thereby affecting fish growth and wellbeing.

Due to the recent startup and small size of the fish (tilapia) at project's end, fish growth was not evaluated in the Danish trials. The system applied is with 100% recirculation. Preliminary results indicate that stocking small fingerlings (0.3 g) into a tank prepared for end harvest level is not suitable for securing maximum feed intake and optimal growth rates. Fish growth has been slow and keeping the water temperature above 20°C in the system has been difficult at times during winter, despite 23°C set for the air temperature in the greenhouse. Heating pipes therefore need to be installed at the bottom of the fish tanks and controlled by thermostats to secure a better and stable growth rate of the fish.

3.1.3. Recommendations and guidelines, communication activities

The system applied in Norway was 100% recirculated, i.e. there is no effluent from the system and water is added only to replace evaporation and flushing of particles from filters. *Recommendations for water quality*, recommended levels for recirculation aquaculture should be followed, to support good growth and survival of the fish, including efficient particle filtration, monitoring pH and maintain pH close to 7.0, keep the fish density below 25 kg/m³ if only aeration is used and no oxygenation of the water. Measure water quality parameters from nitrification once every week (TAN, NO₂, NO₃), and monitor chloride levels for maintaining at 100 mg/l. A high difference in the growth rates of brown trout and rainbow trout in the system was observed, indicating the importance of *selecting the appropriate fish species* for such systems.

Results from the Icelandic studies shows that *better growth of tilapia was achieved at lower*

(80%) as compared to higher (90% and 100%) levels of recirculation. The results furthermore indicate that *re-used effluent water from fish farming operations can be used directly* (without 100% recirculation) for cultivation of different plant species, using local material in a simple and cost effective system for filtration of the water. *Production of vegetables or fruits in the nutrient rich effluents from aquaculture operations may therefore be an interesting option* for smaller producers of fish in land-based aquaculture in Iceland. This may be of particular interest for operations with access to geothermal water resources allowing the production of a broader spectrum of plants, even exotics plant commonly produced only at lower latitudes.

Results from the Danish studies (100% recirculation) emphasize the need for *stocking fingerlings into smaller tanks for later transfer* to tanks prepared for harvesting size of the fish. In addition, selecting a certain air temperature in the greenhouse may not be sufficient for *maintaining the appropriate water temperature* during cold winter months and/or warm summer months, thereby compromising fish growth and wellbeing.

3.2. Results from WP2 studies: Plants

3.2.1. Summary of report on effluents and plant growth Iceland

Two distinct series of experiments were carried out in Iceland. One in 2012 testing growth of lettuce, basil, spinach and rocket in the effluent from aquaculture production of Arctic char and Tilapia with no recirculation of the culture water. And series of three experiments carried out in 2013-2014 for testing the effects of different recirculation levels (80%, 90% and 100%) on the growth of lettuce and mizuna. The experiment carried out in 2012 also included a comparison of flow-through tap water, biofiltered water, unfiltered water and a recirculating hydroponic nutrient solution for plant growth in three different media, pumice, Hydroton and hydroponic raft medium.

The main results from the 2012 study show that although the germination rate for the rocket seeds were high, the plants were very small and fragile compared to the lettuce and basil seedlings when planted into the experiment boxes. This may explain the low survival rate of the rocket seedlings in the experiment.

Results from the 2013-2014 study show that lettuce grew well at 80% (Figure 3.2-1) and 90% recirculation level, but for some reason suboptimal at 90% recirculation. This may be explained by slightly lower levels of nitrate and phosphate at 90% recirculation as compared to the other recirculation levels. Highest growth of mizuna was obtained at 90% recirculation, but overall the growth of mizuna poor, indicating that this plant might be difficult to grow in aquaponics systems.



Figure 3.2-1:
Hydroponic tanks in Matorka's experimental aquaponics system in Fellsmúli, Iceland.

The total weight of lettuce at endpoint was similar at 80% and 100% recirculation, but considerably lower at a recirculation level of 90%. Endpoint leaf weight increased with a higher level of recirculation, possibly reflecting the increased concentration of nutrients in the water. The weight of leaves and stem length also tended to increase with a higher level of recirculation (table 3.2-1).

Table 3.2-1:

Lettuce growth during the course of the trials. The table shows average values for five plants at each level of recirculation.

Level of recirculation	80%	90%	100%
Plant weight at endpoint (g)	159.8	217.8	208.8
Leaf weight at endpoint (g)	125.4	146.2	157.6
Stem weight at endpoint (g)	34.4	71.6	51.2
Dry root weight at endpoint (g)	1.2	1.5	1.3
Increase in stem length (mm)	179.8	293.0	259.4
Increase in leaf number (N)	24.8	20.0	23.8
Increase in leaf length (mm)	4929.0	4166.6	5337.4

Table 3.2-2 gives an overview of the growth of mizuna during the trials. There was a marked difference in the growth of mizuna between different levels of recirculation, with the best growth obtained at 90% recirculation. Compared to the growth of lettuce, mizuna did not grow well and many plants did not grow at all or showed signs of nutrient deficiencies. When the roots of the mizuna plants were examined, they were found to be covered with brown sludge, presumably bacteria, which may have reduced nutrient uptake. The roots of the lettuce did not seem to be affected in the same way.

Table 3.2-2:

Mizuna growth during the trials. Average values for five plants at each level of recirculation.

Level of recirculation	80%	90%	100%
Leaf weight at endpoint (g)	8.8	88.8	22.8
Dry root weight at endpoint (g)	0.4	1.6	0.9
Increase in leaf number (N)	5.0	13.8	8.8
Increase in total leaf length (mm)	458.2	3512.4	1561.0

Norway

At Bioforsk/NIBIO Landvik, the aquaponics facility has been running since March 2014. Figure 3.2-2 gives an overview over plant growth experiments in 2014 and 2015

Plant trials spring 2014 (trial 1):



Plant trials with elder plants implemented in aquaponics spring 2014 (trial 2):



Plant trials autumn 2014 (trial 3):



Plant trials spring 2015 (trial 4):

**Figure 3.2-2:**

Plant growth in 2014 and 2015 trials at Bioforsk/NIBIO.

The Norwegian trial 1 (2014) investigated plant growth for two types of lettuce (Lollo bionda and Lollo rosso) and swiss chard. It was observed chlorosis and pale colours in both red and green varieties of lettuce (figure 3.2-3). Plant size was also smaller than controls given standard hydroponics fertilisation (figure 3.2-4). Signs of nutrient deficiencies were seen in young as well as old leaves. At the endpoint of the study, there were observed a great difference in plant growth (Figure 3.2-5).



Figure 3.2-3:

Nutrient deficiencies shown on green lettuce 'Lollo bionda', red lettuce 'Lollo rosso' and Swiss chard, trial 1 (April 2014). Photos: Siv Lene Gangenes Skar, Bioforsk/NIBIO.



Figure 3.2-4:

Plants of similar varieties and age grown in Hydroponics (left) and Aquaponics (right), trial 1, May 2014 Photos: Siv Lene Gangenes Skar, Bioforsk/NIBIO.



Figure 3.2-5:

Differences in nutrient status, plant growth and development in the systems, hydroponics (left) and aquaponics (right) at the endpoint of trial 1 (2014).

Another plant study (trial 2, 2014) was performed to study how elder plants were growing in the aquaponic water. Measurements were performed on nutrient deficiency symptoms and plant growth. Plants were observed at the start of the experiment and weekly during 6 weeks. The plant species tested were dill (*Anthemum graveolus*), three different lettuce varieties ('hjertesalat'/mini Romano, crispy and 'Lollo rosso') parsley (*Petroselinum crispum*) and tomato (figure 3.2-6).

Water nutrient analyses showed low content of nitrogen for plant growth (table 3.2-3). During the experiment, leaves and roots were observed. It was observed well developed root system and also new roots emerging from the base of the plant (figure 3.2-7). Low nutrient content was measured in the fish effluent water (table 3.2-3). Cultivation temperature was found below optimum for plant growth.

Table 3.2-3

Registration of experimental conditions and biomass production under trial 2, 2014

(# = "number of").

Time	Input	Measured cultivation conditions during trial 2						Biomass	
Date	Feed per day, g	Temp. °C	pH	O ₂ mg/l	TAN-N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	# fish (total, 4 fish tanks)	# plants (total in the trial)
14.04	180	13,3	7	8,2	0,237	0,124	-	392	168
26.04	200	15,2	7,2	8,4	0,171	0,254	5,6	386	168
02.05	200	15	7	9,1	0,163	0,055	3,7	385	168
05.05	200	14,8	7	8,5	0,162	0,041	5,6	384	168
08.05	200	14	6,9	8,4	0,199	0,07	5	380	168

**Figure 3.2-6:**

Plants showing deficiency disease after growing 49 days in an unbalanced aquaponics system (trial 2, 2014) at the top: dill, 'hjertesalat'/mini Romano and tomato, next row: lettuce, parsley, lollo rosso). At the bottom: Overview over the aquaponics floating bed. Photos: Siv Lene Gangenes Skar, Bioforsk/NIBIO.



Figure 3.2-7:

The plant roots are well developed in an aquaponics system. Photo: Siv Lene Gangenes Skar, Bioforsk.

During trial 2 (2014), it was observed that some varieties performed better than others (table 3.2-4). Crispi lettuce showed interesting results by on average having more than two times higher yield in aquaponics compared to hydroponics system. Similar results were observed for parsley.

The lettuces ‘Hjertesalat/mini Romano’ and Lollo rosso, and dill developed at nearly the same rate in hydroponics and aquaponics. Tomato plants were growing better in hydroponics. Based on these results we chose ‘Crispi’ for our trial 4 as a promising vegetable plant for Nordic aquaponics.

Table 3.2-4:

Plant growth for elder plants in aquaponics (Start 11 of April 2014, End 8 of May 2014)

Plant selection		unit	Days in system	Aquaponics	Hydroponics
'Hjertesalat'	Start, roots	cm	0	45,8	43,8
	Roots	cm	13	40,7	41,8
	Roots	cm	19	49,3	44,8
	Start weight	g	0	222,7	234,0
	Weight	g	13	458,2	432,0
	Weight	g	19	561,3	-
	End weight	g	27	322,7	-
Crispi lettuce	Start, roots	cm	0	38,5	51,1
	Roots	cm	13	57,2	40,2
	Roots	cm	19	48,0	48,5
	Start weight	g	0	157,6	142,56
	Weight	g	13	378,5	236,4
	Weight	g	19	444,2	286,51
	End weight	g	19	688,9	250,64

Plant selection		unit	Days in system	Aquaponics	Hydroponics
Lollo rosso	Start, roots	cm	0	39	47
	Roots	cm	13	52	47
	Roots	cm	19	53	47
	Start weight	g	0	131,95	165,66
	Weight	g	13	330,9	328,5
	Weight	g	19	471,25	469,0
	End weight	g		-	-
Dill	Start, roots	cm	0	39,3	40,8
	Roots	cm	13	41,0	38,3
	Roots	cm	19	47,3	45,0
	Start weight	g	0	40,86	42,5
	Weight	g	13	117,3	116,3
	Weight	g	19	185,4	222,7
	End weight	g		322,7	-
Parsley	Start	cm	0	33,4	36,4
	Roots	cm	13	36,2	35,4
	Roots	cm	19	38,7	40,0
	Start weight	g	0	52,8	45,3
	Weight	g	13	156,7	96,9
	Weight	g	19	223,8	134,8
	End weight	g	-	-	-
Tomato	Start	cm	0	51,7	56,3
	Roots	cm	13	50,8	56,5
	Roots	cm	19	51,8	57
	Roots	cm	27	-	-
	Start weight	g	0	47,5	61,7
	Weight	g	13	137,0	164,3
	Weight	g	19	176,9	296,1
	End weight	g	19	107,8	99,3
	End weight	g	27	231,2	617,3

During the experimental studies in early winter 2015 (trial 3, 2014) in November and December, tip burn was observed in a period with high humidity (cloudy and rainy weather). The variety Hilde II was found to be very susceptible against tip burn with clear necrotic leaf tips while 'Crispi' was observed to be very resistant with only negligible symptoms.

In 2015 there was a new set-up for study (study 4, 2015), now the system had matured during the last year and the fish biomass had increased dramatically. The study showed, that the effect of nitrogen in the form of ammonia (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) and other nutrients given by the feed, is depending on fish size and how much feed is supplied. Based on results of the first studies in spring 2014 (trial 1 and 2), the Norwegian team decided to have only one crop (lettuce 'Crispi'), and measure mass balance in the trout aquaponics at Bioforsk/NIBIO Landvik (trial 4). During the experiment, plant area increased with increased fish biomass and availability of nutrients.



Figure 3.2-8:

Lettuce variety 'Crispi' in production in trout aquaponics facility at Bioforsk/NIBIO Landvik. Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO

Results of trial 4 (spring 2015, fig. 3.2-8, tab. 3.2-5) gives a ratio fish:plants of 1:4.3, and this production system is nearly 100 % closed. Plants were growing well, and it was observed that in week 7 to 8, the plants accelerate growth in kilos, when the natural light radiation increased (date 13.feb and 20.feb). For optimum quality of plants, it is recommended to harvest after about 7-7.5 weeks from seeding.

In our analysis in trial 4 (2015), plants had a dry content of 3.34 %, fish 30 % and feed 95 % (see Appendix for more details). The nitrogen content in the plants was 4.84 %, and they had a phosphorus content of 0.68 % given from the effluent water.

Table 3.2-5

Results for trial 4, 2015.

Date	Production											Input		
	Fish				Plants				Sludge			Feed		
	Biomass in tanks g	Out g	N g	P g	Biomass in beds g	Out g	N g	P g	Produced litres	N g	P g	Supplied g	N g	P g
30.jan	42 044				8 349									
06.feb		6 940	211	15		10 252	17	2	124,6	59	14	4 910	355	65
13.feb		7 516	228	16		13 616	22	3	122,4	26	10	4 500	325	59
20.feb		4 702	143	10		16 482	27	4	128,2	45	11	4 920	355	65
27.feb		8 538	259	18		11 020	18	3	109,7	100	29	5 460	394	72
06.mar		477	14	1		9 526	15	2	117,1	57	16	4 900	354	65
13.mar	34 718				26 139	10 900	18	2	133,5	65	18	5 600	404	74
SUM		28 173				71 796								
Production	20 847	634	45		89 586	145	20		735,5	351	97	30 290	2187	400

During the production, small amount of sludge was taken out of the system, with valuable nutrients for plants if treated right (based on own observation, (figure 3.2-9)).



Figure 3.2-9:

'Crispi' lettuce in a test with plant growth in sludge water (1530 $\mu\text{S}/\text{cm}$) to left, and aquaponics water (1530 $\mu\text{S}/\text{cm}$) to the right Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO.

Trial 4 (2015) from 16th of January to 13th of March, shows that lettuce 'Crispi' can successfully be produced with only fish feed as an input (figure 3.2-11). With a production time of 7 weeks, 3 weeks in nursery (fish water in separate aerated tanks), and 4 weeks in the aquaponics production tanks connected to the fish. The whole production time for the plants, are in aquaponics water.

Plant growth during these weeks is shown in figure 3.2-10. The root was growing about 16 centimeters in this period, and reached a maximum after 49 days. The plant diameter increased approx. 13 centimeters, and at the harvest, the plants had reached over 30 centimeters. The plants had a dry mass percentage for roots between 3.12 and 3.62 and for leafs 3.20 to 4.13 during this growth period, with highest in the end of the trial.

Results showed that when the plants were transferred into trout aquaponics, the roots started to grow more than the stem and leaf in the first days. After 30 days, roots and stem/leaves were growing nearly at same growing rate. After 47 days, the growth decreases, and harvesting of the plant is recommended (fig. 3.2-10).

Plant growth in an Norwegian aquaponics

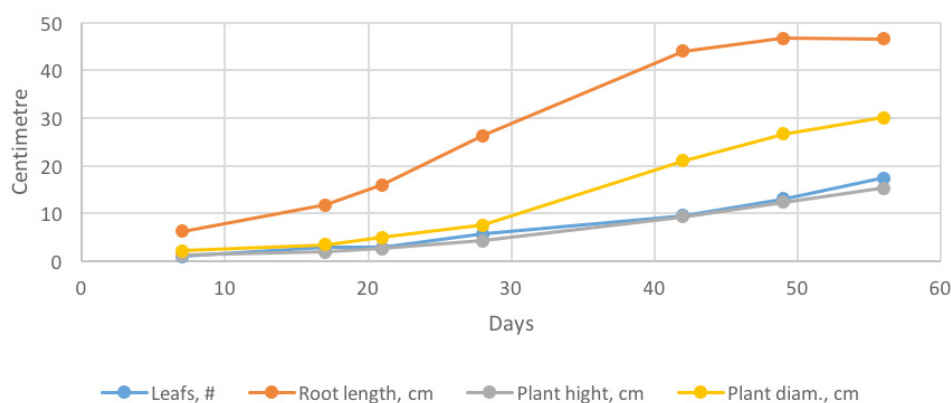


Figure 3.2-10:

Results from plant growth in trial 4 (2015).

Table 3.2-6

Water tests during trial 4, 2015 (# = "number of").

Date	Temp. °C	pH	PO ₄ -P mg/l	Cl- mg/l	TAN-N mg/l	NO ₂ -N mg/l	NO ₃ -N mg/l	Feed, g	# plants, m ²
23.01	15,6	6,96	2,97	117	0,122	0,237	98,8	780	672 / 20
02.02	16,5	6,94	2,98	94,6	0,098	0,168	43	700	672 / 20
06.02	16,7	6,95	3,13	99,1	0,114	0,178	98,8	700	672 / 20
13.02	16,5	6,96	3,54	94,8	0,1	0,151	123,6	600	672 / 20
27.02	17	6,88	4,17	96,8	0,085	0,196	160,4	700	672 / 20
06.03	16,1	6,87	4,1	81,9	0,062	0,147	66,5	800	672 / 20
13.03	16,5	6,9	5,1	79,6	0,089	0,185	128,4	800	672 / 20

Results from plants growing in trout aquaponics and the water conditions during trial 4, are shown in table 3.2-6. Phosphorus is slightly building up in the system, chloride is decreasing and nitrite is more or less stable.

Figure 3.2-11 shows our results of water analysis for nutrient content in the Norwegian trout aquaponics over a period of eight weeks. Sulphur (S), calcium (Ca) and sodium (Na) slightly builds up in the system, silicon (Si) is building up the two first weeks in February and reaches a top 13th of February and then going down to stabilize a week after. The other nutrients (P, K, Mg, N, Mn, Cu, Zn, B, Fe, Al and Mo) are more stable or reduces slightly these weeks, and indicates that the plants are using them for healthy plant growth.

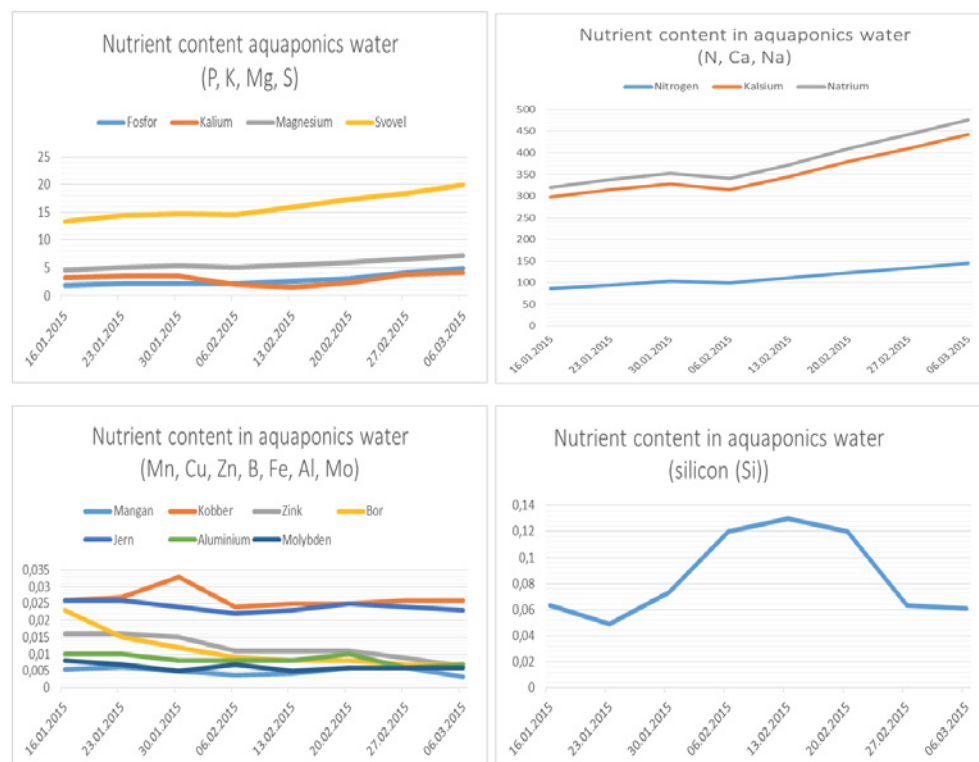


Figure 3.2-11a

Results from water analysis of nutrient content over eight weeks in Norwegian trout aquaponics, under trial 4 (2015) for P, K, Mg, S, N, Ca, Na, Mn, Cu, Zn, B, Fe, Al, Mo and Si. Concentrations in mg/l.

In plants, the nutrient content is a little different from the trout aquaponics water (figure 3.2-11a). The uptake of iron (Fe) and aluminum (Al) decreased in the first weeks of trial 4 (2015). For zinc (Zn), manganese (Mn) and calcium (Ca), the plant increases their uptakes of these nutrients during grown for 3 weeks.

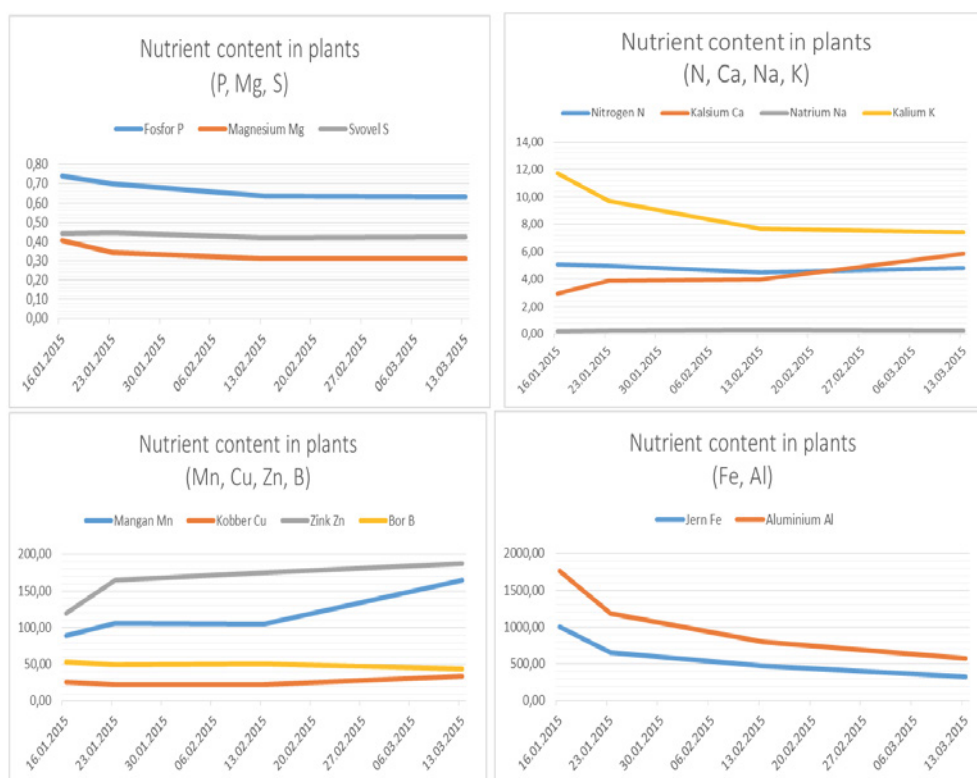


Figure 3.2-11b
Nutrient content in plants, grown in trout aquaponics (trial 4, 2015). Concentrations in mg/l.



Figure 3.2-12:
Healthy 'Crispy' lettuce (trial 4, 2015) in trout aquaponics in Norway. Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO.



Figure 3.2-13:

New plant products for trout aquaponics, here shown by mix bouquets of different lettuce varieties. Photos: Siv Lene Gangenes Skar, Bioforsk/NIBIO.



Figure 3.2-14:

Plant trial 4 (2015) at Bioforsk Landvik. Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO.

Trial 4 (2015) resulted in production of a sale volume of 89.8 kg lettuce based on 20 square meters, with an input of fish feed of about 40 kg over a time period of 8 weeks (table 3.2-8). Plant roots and bad quality plants is not included in the 89.8 kg. Plant roots is approximately 3 – 8.5 % of the plant dry weight, and 5.5 - 7 % of plant wet weight (table 3.2-7).

Table 3.2-7

Results of plant weight (wet and dry) and % of root after 56, 60, 63 and 64 days in an aquaponics unit (trial 4, 2015).

Production time	Dry weight		% root of	Wet weight		% root of
in days	roots	leaves	total plant	roots	leaves	total plant
56	1,18	22,89	4,89	31,88	553,5	5,45
60	0,478	10,47	4,36	23,88	323,63	6,87
63	1,465	15,865	8,45	32,125	444,25	6,74
64	0,465	15,813	2,86	26,75	442,85	5,7

Table 3.2-8:

Measurements results in trial 4 (2015).

Parameters	Unit	Week 1	Week 4	Week 8	Total for 8 weeks
Input fish feed	kg	5,24	4,76	5,90	40,52 kg
Biomass 672 plants	kg	16,84	20,8	37,039	89,6 kg
Plant growth	kg/m ²	0,84	1,24	1,85	3,6 kg
Dry weight, plants	%	3,25	3,62	3,88	3,34 %
Plant weight for sale	kg	9,66	13,62	10,90	89,8 kg
Plant products for sale	#	89	92	94	742 lettuce
Bad quality	#	7	4	2	26 lettuce
Price per lettuce	NOK	10,-	10,-	10,-	7420,-
Price, lettuce	NOK/kg	82,63	82,63	82,63	

The water analysis showed in figure 3.2-11, indicates that the chosen fish feed for trout from the Norwegian feed company Skretting, gave the plants nutrients to grow healthy in the wastewater.

Denmark

Experiments on plants (salad and basil) will take place once the nutrient supply from the fish production has reached a recommended level similar to commercial hydroponics systems.

3.2.2. Summary of report on comparison of results

Production systems and production strategies at the three production sites were very different and a direct comparison of results therefore not relevant.

The main results from the Icelandic trials on the growth of lettuce, basil, spinach and rocket in flow-through effluent water from aquaculture production of Arctic char and Tilapia show that although the germination rate for the rocket seeds were high, the plants were very small and fragile compared to the lettuce and basil seedlings when planted into the experiment boxes. This may explain the low survival rate of the rocket seedlings in the experiment. The results for un-filtered, bio-filtered and nutrient solution was very similar.

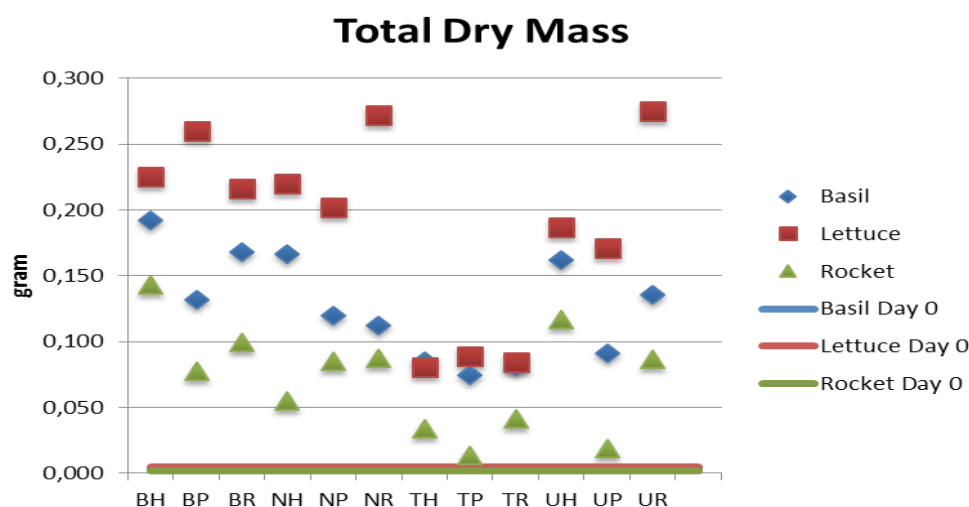


Figure 3.2-15

Changes in total dry mass of plants during the course of the study. Label see table 2.1.1

The results from the study on the effects of different recirculation levels of the effluent water from aquaculture production of Tilapia (80%, 90% and 100%) showed that lettuce grew well (total increase in leaf length mm) at 80% (Figure 3.2-15) and 100% recirculation level, but for some reason suboptimal at 90% recirculation. This may be explained by slightly lower levels of nitrate and phosphate at 90% recirculation as compared to the other recirculation levels. Highest growth of Mizuna was obtained at 90% recirculation, but overall the growth of mizuna poor, indicating that this plant might be difficult to grow in aquaponics systems. Hydroponic tanks in Matorka's experimental aquaponics system in Fellsmúli, Iceland, shown in fig. 3.2-1.

The total weight of lettuce at endpoint was similar at 80% and 100% recirculation, but considerably lower at a recirculation level of 90%. Endpoint leaf weight increased with a higher level of recirculation, possibly reflecting the increased concentration of nutrients in the water. The weight of leaves and stem length also tended to increase with a higher level of recirculation (table 3.2-1). An overview of the growth of mizuna during the trials is shown in Table 3.2-2. There was a marked difference in the growth of mizuna between different levels of recirculation, with the best growth obtained at 90% recirculation. Compared to the growth of lettuce, mizuna did not grow well and many plants did not grow at all or showed signs of nutrient deficiencies. When the roots of the mizuna plants were examined, they were found to be covered with brown sludge, presumably bacteria, which may have reduced nutrient uptake. The roots of the lettuce did not seem to be affected in the same way.

The Norwegian aquaponics facility was first started in January 2014 and in March to June there were done several trials due to plant selection in this type of systems. Vegetables like Swiss chard and lettuce did quite well in the system even though there were lack in the system of nutrients (trial 1 and 2, 2014). The fingerlings were too small to give the plants what they needed, and different symptoms appeared (figure 3.2-3 and 3.2-6). Later, the fish have grown bigger and needed more feed, and consequently the plants got more nutrients. At that stage, the plants were fresh, healthy and green, with no signs of nutrient deficiency. Nothing was added but fish feed.

A successfully lettuce production (figure 3.2-14) can take about 6-7 weeks in an aquaponics system, with nursery for three weeks and in the system in four weeks. It is important to cover all water for sunlight for preventing plant algae growth in the system. Algae can use a lot of nutrients the produced plants should have, and also to prevent a boom with Sciarid flies.

Biological control is recommended and *Hypoaspis miles*=*Stratiolaelaps scimitus* is well proven for this, approximately 1000 mites/m².

3.2.3. Recommendations and guidelines, communication activities

Results from the Icelandic studies indicate that the nutrient composition of fish farm effluent can be used directly for growing hydroponic vegetables. Growth in bio-filtered effluent was even higher than growth in a standard hydroponic solution. There was no consistent difference in plant growth when using different growth media, pumice or Hydroton. Lettuce growth was good at an 80% recirculation level and similar at 100% recirculation, but for some reason, suboptimal at 90% recirculation. This may be explained by slightly lower levels of nitrate and phosphate at 90% recirculation.

Mizuna growth was higher at 90% and 100% recirculation, compared to 80% recirculation. For some reason, the growth of mizuna was higher at a 90% recirculation level. Overall, mizuna growth was poor which indicates that it might be difficult to grow in aquaponics systems.

Production of vegetables or fruits in the nutrient rich effluents from aquaculture operations may be an interesting alternative as a side-production, especially for smaller producers of fish in land-based aquaculture in Iceland. Bulk production into already existing markets may not sound feasible and hence, specific markets such as organic products and/or production of exotic herbs and other vegetables currently only available from import may be an option based on higher value of such products. However, the current regulations restrict the use of nutrients from fish farming operations for the production of organic food products. Production that could replace the currently imported green growth, based on the use of the geothermal water resources available, and providing access to warmer water for the plant cultivation may therefore be an interesting option that is worth further investigation.

Results from Norway show that plants grow well in cold freshwater wastewater from fish production in recirculated aquaculture systems on land. From our experience so far, plants can efficiently exploit nutrients from fish wastewater (3.2-10). The recommendations are for new producers to collect as much knowledge as possible about the system/concept, see how other people are doing this kind of production, and then determine for themselves on the best way for their production, based on their resources, type of land, finances etc. It is important to do this kind of preparation before starting a production.

As a guideline, do first make a market investigation due to what product the costumers want. In Norway, they want the most known vegetables like different kind of lettuce and different herbs, which are great products to produce in this kind of Nordic aquaponics, with cold-water fish production.

There has been an increasing interest in aquaponics after several media stunts, like a reportage in evening television news in Norwegian television NRK 9th of April 2014 to NRK radio interviews. There has also been several articles and publications in newspapers, technical literature and on the internet. As results of this, several people have visited the aquaponics facility at Bioforsk Landvik. Bioforsk Landvik has also arranged workshops with people from Norway, Nordic countries and Europe representing companies, both green and blue industry, universities (students and researchers), consumers and governmental bodies and volunteers (figure 3.2-16). All the visitors and the participants were positive in their feedback after the different activities related to aquaponics.

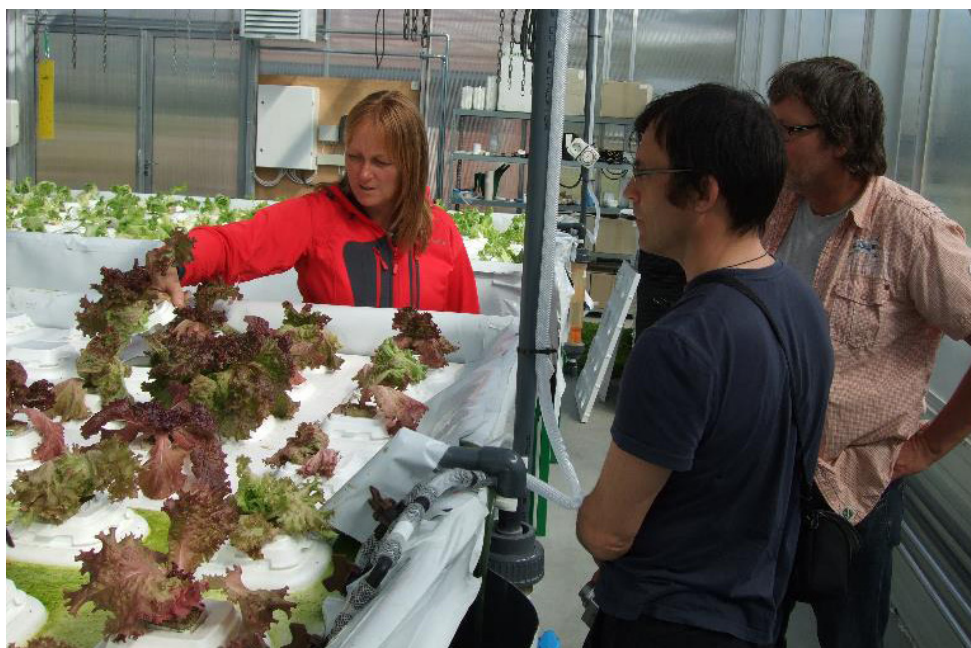


Figure 3.2-16:

Visitors to aquaponics facility at Bioforsk Landvik 26th of June 2014. Photo: Erling Stubhaug, Bioforsk/NIBIO.

For future prospects, the aquaponics is an excellent system to produce food in urban areas and areas with very poor soil and limited water resources. It seems that the world is running out of nutrients and clear water, and aquaponics is a system that recycles and reuses nutrients and conserves water. Aquaponic systems are extremely productive with 300 000 lbs per acre (136 200 kg/acre or 551 200 kg per decar (1000 square meter)) of annual production outside in the tropics or at controlled environment agriculture in temperate regions (ANE, 2012).

A critical mass of interest and knowledge is increasing to a point where aquaponics will soon take off in the commercial sector and expand at an exponential rate of the hobby level.

3.3. Results from WP3 studies: Technology

3.3.1. Summary of dimensioning and mass-balance (data report as attachment)

System specific recommendations

Iceland

The main criteria when designing the experiment was that it could be scaled up to a commercial facility that could be viable for the average fish farmer. Furthermore, we took notice of the advantage of using the natural resources here in Iceland. This means that the incoming water for the system was not filtered since it is pure spring water and geothermal water was used to obtain the desired temperature.

A pumice filter was used in an attempt to create a cost effective particle and bio filter using local material. Due to the natural water resources available in Iceland, currently there are no 100% fresh water recirculation systems used in Iceland but a growing number of semi recirculation systems in use made clear the need to test the viability of a aquaponics system using less than 100% system. Hence, 80% and 90% recirculation systems were compared to 100% recirculation. Both Lettuce and Mizuna were grown in 80% and 90% as compared with 100% recirculation system. Lettuce did quite well in all systems but the Mizuna was not viable

in any of them. The conclusion drawn from this study is that the lettuce has a potential as a crop for farms using partial recirculation systems.

The floating raft system used in the trials probably needs more space than both the nutrient film technique and the media-filled bed system. This may be an issue when considering aquaponics design since most if not all aquaponics systems in the northern hemisphere are indoors. Furthermore, in this regard it might be worthwhile to look towards multiple layer systems to minimize the floor space.

Norway

The system built is a deep water culture (DWC) system. A flow chart of the system is shown in figure 2.2-2. A technical drawing of the system is shown in figure 2.2-3. The system was designed as simple and flexible as possible, with a common pump sump with only one pump for transport of water. Water treatment is kept on minimum, but with focus of critical processes like particle removal, biofiltration (nitrification), pH-adjustment/alkalization and aeration. More details regarding water treatment will be described in chapter 3.3.2.

pH-adjustment. In order to counter-act the alkalinity consumption from nitrification and fish metabolism, calcium carbonate (CaCO_3) slurry was added by an automatic dosing system.

During the period of sampling and normal operation (16.01.2015 to 13.03.2015), a set point of pH 7 was programmed into the pump-regulator. During the period, the carbonate demand increased, so the capacity of the pump had to be increased from 330 l/min to 750 l/min).

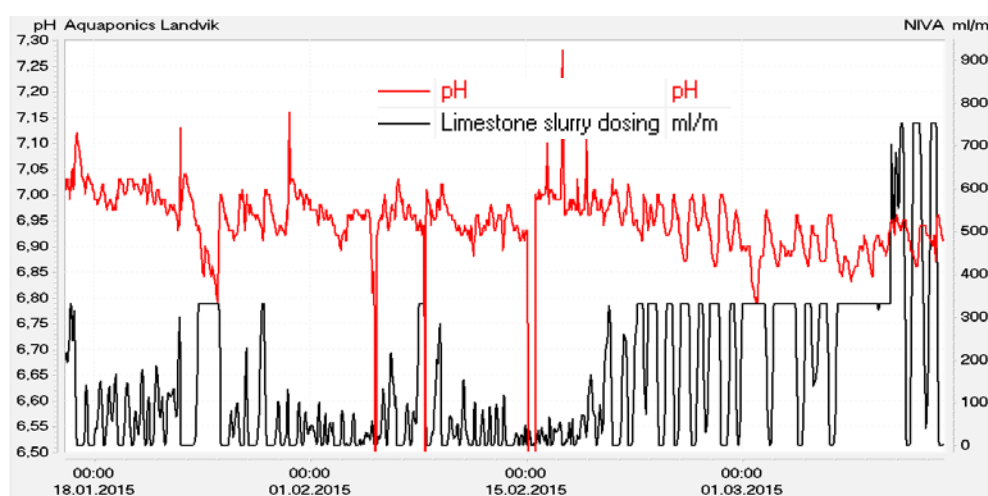


Figure 3.3-1:

pH values and limestone slurry dosing in the period from 16.01.2015 to 13.03.2015. The dosing frequency was fluctuating due to concentration variations in the limestone slurry. The major pH drops were caused by an electronic failure.

Temperature control. The temperature in the recirculating water was controlled by a heat/cooling pump in the circuit. The temperature was set to approximately 16 °C. Actual temperature readings are shown in figure 3.3-2.

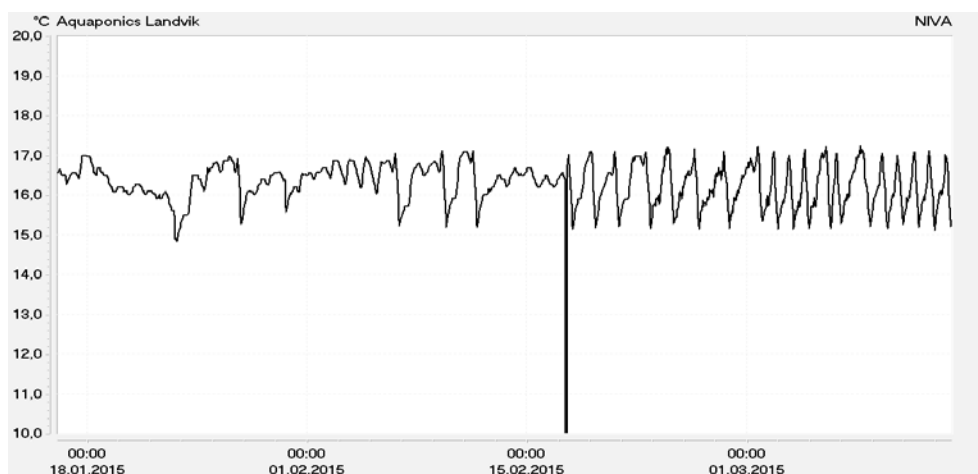


Figure 3.3-2:

Temperature in the circulating water during the period from 16.01.2015 to 13.03.2015. The drop on the 17. February was caused by maintenance of the temperature sensor.

Oxygen control. As indicated in figure 3.3-3, the oxygen was high throughout the period, with a slight increase with time.

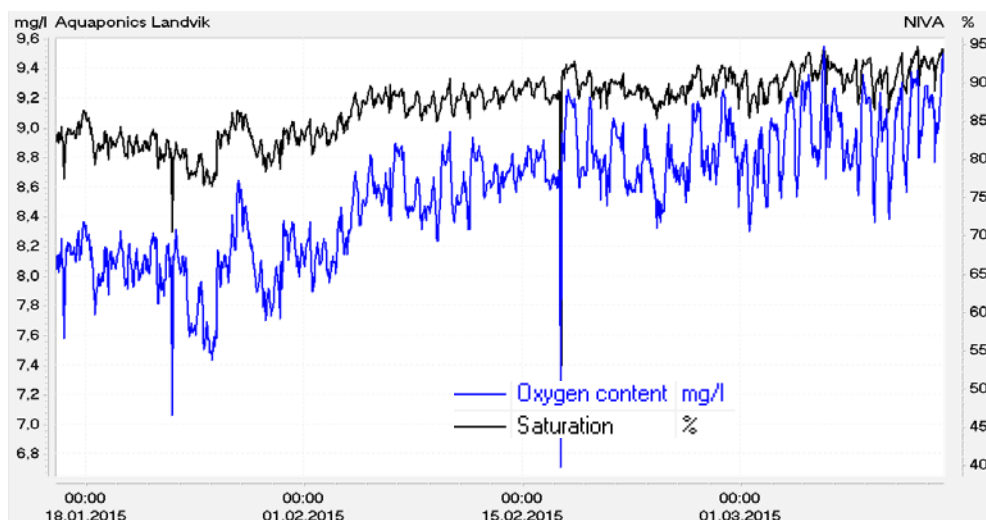


Figure 3.3-3:

Oxygen content in mg/l and % saturation in the circulating water in the period from 16.01.2015 to 13.03.2015. The oxygen sensor was placed in fish tank no. 1.

An 8-week sampling campaign for preparing mass balances on nitrogen and phosphorous has been conducted. For mass balance calculations input to the system was logged as fish feed, and production (output) from the system was logged as fish growth, plant growth and sludge production. Parameters used for mass balance calculations were nitrogen and phosphorous. The period used for mass balance calculations were from 30th January till 16th March.

From the summary of results in table 3.3.1 we can see that there was a discrepancy between input and output to the system. On a nitrogen basis the production of plants, fish and sludge and the accumulation of N in system water accounted for 83,7% of the N input from the fish feed. For phosphorous, the production (as fish, plants, sludge, accumulation) accounted for

46% of the input as fish feed. Possible sources for this discrepancy (especially for P) were bacteria production (fixed bacteria film on surfaces) or algal production. From the results it is evident that more P is fixed to the particles in the sludge relative to N. Insufficient sampling leaving the biggest particles (sediment) of the sludge will contribute to the discrepancy of P more than for N.

The system produced 4,3 times as much plants as fish measured as wet weight. During the experimental period, the nutrition from sludge was not used in the production. If we consider the content of N (145g) and P (20g) in the plants produced, and relate this to N and P accumulation in system water and in sludge (N: 351g+701g)

(P: 97g+22g) it should be evident that the potential for producing even more plants is there. Other possible limiting production factors will be further analyzed (as plant macro- and micronutrients).

Table 3.3.1:

Summary of mass balance calculations performed in the Norwegian production system (42 days). ¹⁾

	Production Weights kg	Nitrogen g	Phosphorous g
Input			
Fish feed used	30,3	2187	400
Output			
Fish production	20,8	634	45
Plant production	89,6	145	20
Sludge production	736	351	97
Accumulated N and P in system water		701	22
Sum output		1830	184

¹⁾ For details see appendix.

Denmark

A research design is in the making, which besides the NOMA partners, is also being coordinated with aquaponic researchers in Spain and hence prepare for common journal paper publication. Once the fish biomass is sufficient in relation to the plant production, analysis on dry weight, wet weight in plants as well as their nutrient composition compared to the protein content in the fish feed and the water quality parameters targeted, will be conducted.

General recommendations

Specific conditions in the different countries have been of importance regarding design and operation of the different systems. For example, the availability of natural water resources and thermal energy in Iceland, may favor semi recirculation over 100% recirculation. High degree of recirculation will be more important in countries with limited water and energy resources. Also the use of local materials, like pumice filters, may decide water treatment design. More on water treatment, and design of water treatment units, are presented later in this chapter.

In this project, three different aquaponics systems have been designed, built, and operated over time. Experience shows that it is possible to operate the systems and produce first class fish and plants (salad) over long time, even with 100% recirculation without having significant negative effects from accumulating substances in the breeding water. Design data are given in table 3.3-2. In addition to these three aquaponics system a trial was conducted in Iceland using flow-through system, see section 2.2.1. These data can be used as a basis for up-scaling of the systems to commercial units.

A mass balance on nitrogen and phosphorous was conducted for the Norwegian system.

On a nitrogen basis, the production of plants, fish and sludge, and the accumulation of N in system water, accounted for 83,7% of the N input from the fish feed. For phosphorous, we were only able to find 46% of the input as outputs. Possible sources of discrepancies are discussed earlier in this chapter. The system produced 4,3 times as much plants as fish measured as wet weight. There is a potential of producing even more plants by utilizing the nutrients in water and sludge better. Summary of design parameters of the aquaponic systems by the partners in the NOMA-project is shown in table 2.1-1.

3.3.2. Recommendations on water treatment technology

System specific recommendations

Iceland

A low-cost and simple setup was used for biofiltration, using an on-site developed pumice filter. The extensive surface created by the locally available pumice created a considerable biofilm in the system. The floating raft system is very beneficial in this regards. However, attention should be paid to the filter system as a whole, mainly the back flushing system needs to be automatic since manual back flushing once or twice a day did not prove sufficient.

The water treatment technology used was a relatively simple and cost effective one, as initially aimed for. Testing the effects of different recirculation levels in the same system influenced the complexity of the setup since there was a considerable exchange of water. Particle removal and sludge handling was done by using swirl separator followed by pumice filter in the second stage. No UV-treatment or sedimentation of effluent water from fish tanks was used in the trials.

Aeration/ CO_2 -stripping/oxygenation was all accomplished by using two-step airlift system. This was based on air diffusion through air stones. The airlift system worked very well. It is easy to operate, simple and cost effective.

In Iceland, the aquaculture operations are most likely in no need for a RAS system because of ample supply of water and cheap energy. They are not going to add on such a system just so they can operate an aquaponics farm. However, most of them are moving towards PRAS (partial reuse aquaculture system) and if the effluent from such a system can be used, they are more likely to venture into aquaponics. The treatment of the effluent water (filtering and aeration) prior to entering the aquaponics facility needs to be as simple and low cost as possible. That is exactly what the Icelandic team was trying to achieve with the system design.

Norway

Solid separation. In our system, solid removal was taken care of in two units; 1) swirl separators mounted on the effluent from each fish tank and 2) a PolyGeyser Bead Filter for water polishing. Sludge-water from the swirl separators and the beadfilter was discharged into aerated sludge tanks for mineralization.

Results from the sampling campaign (16.01.2015-13.03.2015) proved the efficiency of the solid separation technology used. The particle content in the system, measured in the sump as suspended solids (SS) and turbidity (FTU), remained low throughout the 8 week test period, with concentrations in the range of 3-13 mg/l and 2-5 FTU, respectively. Trials were conducted to measure the particle separation efficiency of the beadfilter. 24-hours composite samples were collected from influent and effluent on 4 different days. Due to low inlet concentrations, only low differences between inlet and outlet samples were detected. Average separation efficiencies were 28% for SS and 15% for turbidity. These data and operational experience indicate that also the swirl separators are important for fast and gentle separation of larger particles (fish faeces and feed residues). By applying swirl separators on each fish tank, disintegration of larger particles is prevented.

Biofiltration. The applied biofiltration indicate sufficient nitrification in the system. The ammonia ($\text{NH}_4\text{-N}$) concentrations and $\text{NO}_2\text{-N}$ remained low, while $\text{NO}_3\text{-N}$ accumulated to concentrations of about 100 mg/l (Table 3.3-3). Nitrification will take place in different parts of the system (in the bead filter, in root zones), not only in the biofilter. The importance of the biofilter as nitrifier, compared to other parts of the system, was not studied in the project. It is recommended to include biofilter in the design of aquaponic systems.

pH-adjustment/alkalization. Due to the alkalinity consumption of nitrification and CO_2 production from fish, pH adjustment and alkalization are required. We decided to dose a slurry of micronized CaCO_3 from a tank. The dosing pump was controlled by in-line pH measurement. There are problems with undissolved CaCO_3 .

In addition we experienced the importance of elevating the chloride level in the system. Chloride was added to levels of approximately 100 mg/l.

Water quality development. During a 2 month period of normal operation (16.01.2015-13.03.2015), a intensive sampling campaign were conducted. In table 3.3-3, average concentrations of some important water quality parameters are shown.

Table 3.3-3:

Average values of some important water quality parameters in the periode from 16.01.2015 to 13.03.2015.

pH	TAN Mg N/l	$\text{NO}_2\text{-N}$ mg/l	$\text{NO}_3\text{-N}$ mg/l	$\text{PO}_4\text{-P}$ mg/l	TOC mg/l	Cond. $\mu\text{S/cm}$	Turb. FTU	Cl^- mg/l
6,9	0,097	0,18	100,5	3,6	100,5	1 557	4	100

During this 2 month period, there were no indications of accumulation of metals and other compounds with possible toxic effects in the recirculating water, as indicated in figure 3.3-4. All the compounds were reduced or stabilized, indicating low input of these compounds to the system, efficient uptake in the plants, and/or particle association and withdrawal as sludge. The concentrations of metals and micronutrients were significantly below recommended concentrations for vegetables in hydroponic systems (Hess-Erga and Liltved 2013). Some of the parameters are in the same concentration range as measured in commercial recirculating aquaculture system (RAS) (Hess-Erga and Liltved 2013).

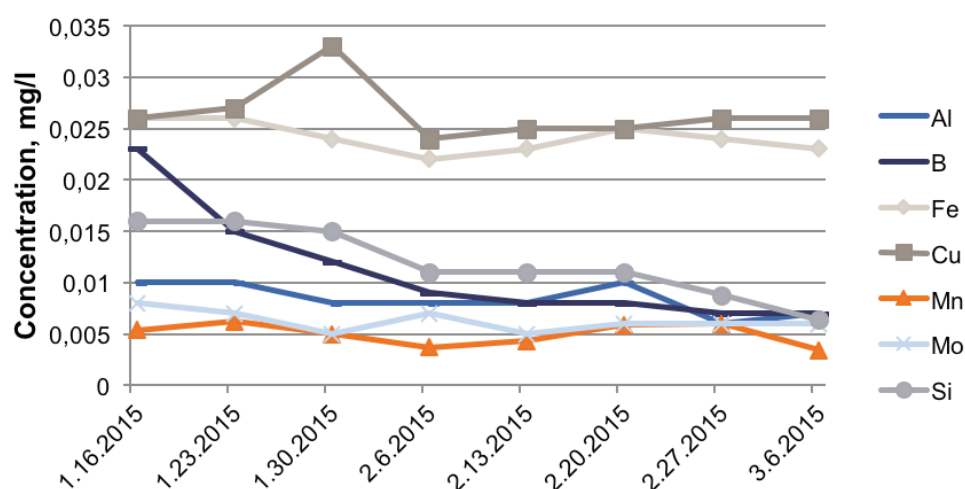


Figure 3.3-4:

concentrations of metals and micronutrients during the 7 week sampling campaign (16.01.2015-06.03.2015).

Other compounds exhibited an increase during the 2 month periode, including Tot-P, TOC, Mg, Na and S, as shown in figure 3.3-5. No significant increase was observed for K. Due to the dosing of CaCO_3 for pH control, the Ca^{2+} concentration increased from 211 mg/l to 297 mg/l during the period (data not shown).

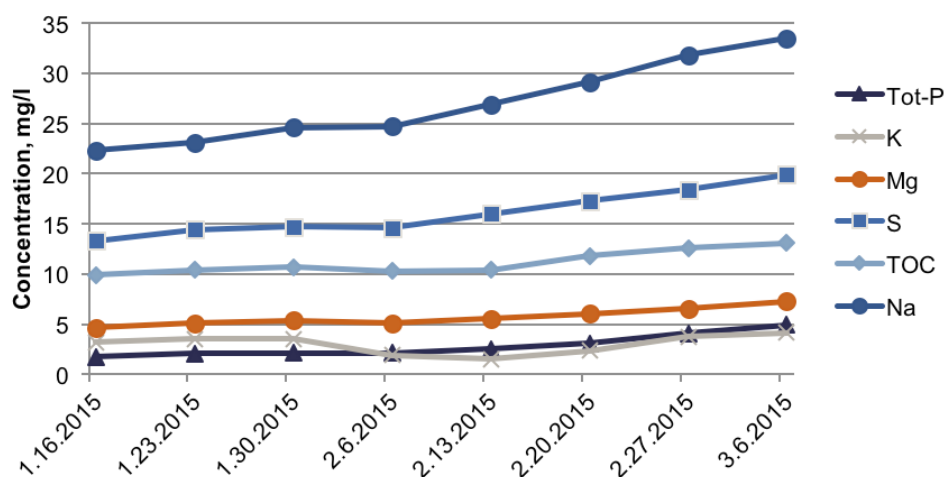


Figure 3.3-5:
concentrations of tot-P, TOC, K, Mg, S and Na during the 7 week sampling campaign (16.01.2015-06.03.2015).

Denmark

The Danish system has indirectly separated the plants from the fish water by growing the plants in pots with soil placed on mobile plant tables and fed by a 'flood and ebb' provision. Hence, some of the challenges in aquaponics with sludge deposits on plant roots and tank floors does not occur in the Danish system.

The mobile plant tables are covered with a plastic folio containing tiny holes for the water to enter when plants/pots are fed. At the entry as well as the exit point on the tables filters are placed to catch any soil sediments when the water runs off. For sedimentation two tanks are installed: one for the fish water flow and one for the plant water flow. The water becomes mixed when water for the plants is called upon, and later returned to the sedimentation tank. After sedimentation the water is sent to a closed pressure filter based on mechanical and biological + microparticle filtration. The biofilter consist of a bead filter, a back wash blower and an automatic backflush system.

pH regulation has not taken place so far due to both a high alkalinity in the water (8,20) and a fish biomass in progress and still small in relation to the amount of water. A dosing pump for pH regulation is installed if necessary. Potassium hydroxide (KOH) is being considered due to already high calcium levels in the water, and potassium deficits have occurred when testing growth of longer-term plants like tomatoes and salads. However, this could be because of the presently small fish biomass, but will be tested when sufficient biomass has been reached.

General recommendations

There is debate about the need for water treatment in aquaponics systems. Based on our experience from the NOMA project, we will give recommendations on which treatment principles and treatment units that should be included, and treatment goals. From the literature, there is focus on solid separation and biofiltration (Timmons and Ebeling 2007).

Solid separation is important to reduce sludge deposit on plant roots and tank floors which may create undesirable conditions and anaerobic microenvironments. Some authors claim that some deposition in the system is favorable due to microbial decomposition and mineralization, thereby releasing nutrients to the water (Timmons and Ebeling 2007). Our opinion is that solid mineralization should be minimized in the system. Solid should be taken out of the system as fast as possible and transported to separate aerated sludge tanks where the mineralization can take place. After sedimentation, nutrient rich decant water, low in suspended solid, can be pumped back to the system.

The two most common solid removal systems used in aquaponics are screen filters and settling tanks. Both screen filters and settling tanks will have limitations regarding removal of smaller particles. The mesh size openings in screen filters will not be below 50-60 µm, thereby allowing finer particles to pass through. Serious deposition problems have also been experienced with settling tanks as sole solid removal method (Timmons and Ebeling 2007).

Biofiltration is primarily installed to convert ammonia to non-toxic nitrate by autotrophic bacteria, which also is an important nitrogen source for plant growth. Heterotrophic bacteria in the biofilter will oxidize biodegradable dissolved organic matter, and compete with the autotrophs of available space and oxygen.

Based on the results from the project, water treatment should be included and designed as in traditional RAS-systems as described in Timmons and Ebeling (2007). In our project, different types of aeration systems were used, like diffused aeration directly in fish tanks and plant tanks, airlift and low plastic column aerators on recirculating water. Different media can be used as biofilters. In our project Kaldnes media, pumice filter and bead filter were used. It is important to have automatic back-flushing of filters to prevent operational problems. A system for pH-adjustment and alkalization must be included at high recirculation ratio and high fish density. The best solution will be to use an automatic dosing system controlled by in-line pH-measurement. By dosing CaCO_3 -slurry, there is little risk of overdosing, but there will build up a sludge layer in the bottom of the plant rafts, containing some phosphorus. If a strong base is used (i.e. KOH), care should be taken to avoid large pH-variations and overdosing. K may be required for plant growth.

3.3.3. Recommendations on environmental impact reduction

System specific recommendations

Iceland

There has been a considerable improvement in regards to solids removal from aquaculture effluents in Iceland. This has been accomplished by using settlement ponds and by improving the farm technology in a way that removes the solids from the water as it leaves the tanks. The recirculation technology is being increasingly implemented into the farms, although in most cases only partially with 70 – 90% recirculation of the culture water from fish tanks.

Issues regarding the nutrients in the water need to be addressed further although the severity of that problem differs very much from one operation to the next. Many farms in Iceland can direct their effluents straight to the ocean or to fast flowing, large rivers where the dilution eliminates the risk of eutrophication. Other farms, where the effluent flows into lakes or small streams, need to rely on biological solutions such as wetlands, large bio filters or aquaponics. Otherwise their farms will be forced to stay small as most of them are today.

Norway

The 100% recirculation of water in the Norwegian system will guarantee no negative impacts on surrounding water bodies. However, there is sludge-water to be treated and utilized. This

sludge comes from back-washing of the filter and the swirl-separators, which was collected in tanks for aerobic stabilization. After several weeks of stabilization, experiments were conducted to separate sludge and clear-phase. Natural biopolymers (chitosans) were used for coagulation and precipitation of the solids. The solid precipitation efficiency of increasing doses of two different chitosans is shown in figure 3.3-6. Most of the nutrients were retained in the clear-phase, and a concentrated sludge were taken out. The nutrient rich clear-phase was recycled back to the system, while the remaining concentrated sludge (approximately 10% of the sludge-water with a dry matter content of 1%) will be treated for use as fertilizer and/or soil improvement.

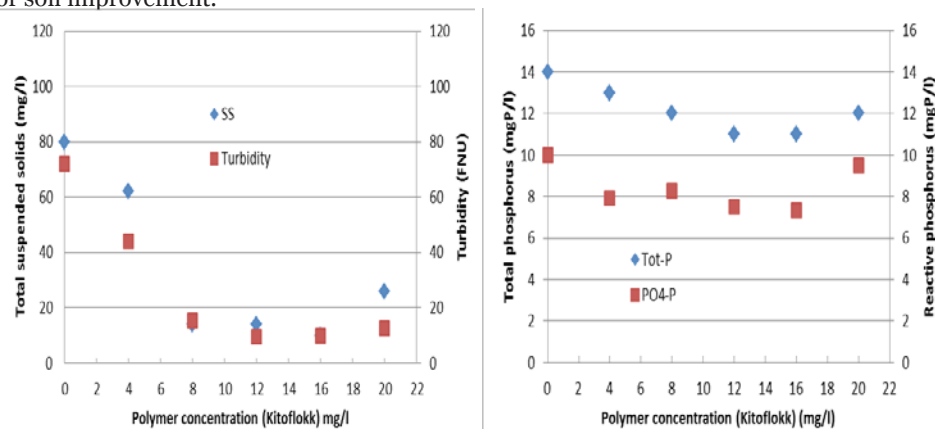


Figure 3.3-6:

Solids (suspended solids and turbidity), and total and reactive phosphorous in the clear-phase after coagulation and sedimentation with chitosan (Kitoflokk).

Denmark

The Danish design has implemented soil for the plants. This means that sedimentation solids can be recycled back for composting and reused in the horticulture production hence closing the resource cycle completely and having a zero discharge into the water environment. Fish tanks placed in the greenhouse, and under the mobile plant tables secured a more stable temperature in the fish tanks, and lowering the need for adding water to cool the temperature as is often the case in intensive aquaculture.

General recommendations

It becomes increasingly clear that the long-term sustainability of many aquaculture operations is dependent on the ability to minimize and mitigate negative environmental impacts. There are 3 main arguments/impacts for restricting in-land aquaculture in the Nordic countries; 1) discharge of nutrients and organic matter to surrounding water bodies, 2) spreading of diseases to wild fish stocks, 3) introducing alien fish species to wild fish stocks. It has been calculated that the production of one ton of rainbow trout produce in total 50 kg N and 9 kg P as waste (Bergheim & Åsgård 1996, Azevedo *et al.* 2011). By introducing aquaponic systems, these environmental impacts can be omitted, partly or totally, dependent on the recirculation ratio.

Independent of recirculation ratio; solid will be produced from solid separation units (sedimentation tanks, swirl separators, filters). The solid has to be stored, treated, concentrated and used. Based on current knowledge and results from this project, the following solid treatment can be recommended:

- Solids from solid separation units are collected in common storage tanks with diffused aeration for aerobic stabilization

- After some weeks of stabilization, a natural polymeric coagulant (i.e. chitosan) can be added (see required dosages in figure 3.3-6), followed by 5-10 minutes of intensive mixing, and 1-2 h sedimentation.
- A submergible pump can be used for extracting the clear-phase back to the aquaponics system, while the concentrated sludge can added slaked lime to pH 11-12 for hygienization, mixed into other bio-remains and used for soil improvement and/or fertilizing purposes (Bergheim et al. 1998).

Aquaponics systems with discharge of water to surrounding water bodies must treat their effluent to prevent environmental impacts.

3.4. Results from WP4 studies: Business designs

3.4.1. Summary of consumer market studies (report as attachment)

A consumer market study of Tilapia was made among chefs both in restaurants and independent consultants. Also, tilapia was provided to Food and Fun, which is every year festival between chefs and Reykjavik's finest restaurants.

The fish was always delivered as a fresh fillets. Some restaurants very often, up to once a week, but other once a month. Siggi Hall chef in Iceland and independent consultant, collected together information from chefs and restaurants. The main result from the three years study is following:

1. The fish - Flavor and texture:
 - A mild flavor and delightful.
 - The fillets has juiciness texture.
 - High quality.
2. The business - Menu and customers
 - Perfect choice for delicious dinner.
 - Special suitable for sushi and sashimi dishes.
 - Perfect for all other dishes, such as grilled, baked and fried.
3. Important external factors— environmental issues, image, publicity:
 - Sustainable production.
 - Grow up in unique and clean water.
 - Low carbon footprint in the production and processing.
 - Ethnicity, Icelandic tilapia has better reputation than Asian tilapia.
 - Quality of the food has high ranking.

In general, fish has a very positive image among consumers in terms of health. This healthy image mainly stems from a high level of proteins and polyunsaturated fatty acids. Also, food safety and quality have become critical issues and fish is one of the most vulnerable and perishable aquatic products. According to restaurants chefs, fish freshness, quality and taste is

one of the most important factors and how the fish is for different dishes. Nauthóll restaurant has had Matorka Tilapia on it's menu for years. "The Tilapia has been a success and has had a very good customer rating" is quote from the owner of the restaurant, Gudridur Johanesdottir.

In the heart of Copenhagen there is a CSA called 'Københavns Fødevarerfællesskab' (KBHFF), which have been existing for some years now with around 1.500 members. These members were targeted for a questionnaire through their website on preferences and willingness to buy fresh fish. The size of the consumer group and the easy access for sending a questionnaire could therefore provide with a fair amount of valuable data. Fish, be it fresh or frozen, are not an option at the moment for the members of KBHFF, and therefore a potential market opportunity for a local aquaponics producer.

To the specific study, it included a questionnaire targeting the 1500 respondents at KBHFF, and 466 replied. Hence, it gives a very good overview and concentrate of the expected opinions found in such alternative food markets.

The questionnaire starts with a short introduction on the four types of fish that could be supplied (Tilapia, Red and Silver, Baramundi, and Pike Peach), their expected price level and type of deliverance such as filet or a whole fish.

The questionnaire is then followed by five simple questions on:

1. How often the member would like to purchase fish?
2. How many people are in the household?
3. Do the member mainly prefer the fish whole or filet?
4. Have the member tasted the listed four fish before?
5. Which section does the member belong to?

Results

466 responded to the questionnaire matching closely to the number of bags sold per week.

55 % said they were interested in buying fish

12 % where not sure

13 % opposed directly

20 % were not specifically pro or against, but supplied instead with explanatory comments.

Among the 20% some responded positively to the option of purchasing fish, but not every week. Others were only interested if it was fillets, or if a course could be provided on how to fillet a fish.

Some did not know the fish species presented in the questionnaire, and a few presented themselves as vegetarians/vegans.

A few replies were simply against fish.

Within KBHFF there is among the members already a fish group promoting fish for sale in the CSA. They informed that before X-mas 2014 they made a sales offer selling organic trout. Only 38 fish were ordered and sold. One explanation for this they said could be that the shop of KBHFF do not have any cooling facilities making it more complicated for the members to handle. The whole distribution and packaging is based on the members own volunteering and handling of the various food commodities. So structural barriers of the CSA packaging facilities could have some influence on the respondents on the idea of purchasing fish.

The result of the questionnaire indicates that for any aquaponics producer to start up selling to a local CSA, it would be a good idea to do some promotional initiatives like pre-visiting the production, showing and informing about the products, understand the organization structure of the CSA and its decision-making.

3.4.2. Three commercial production models

Iceland

A simple home-made system was constructed at the Icelandic site, with the overall aim to test if a simple, cost-effective aquaponics system could be combined with an already existing aquaculture production.

Upscaling aquaponics system and design parameters are shown in table 3.4.2-1. The system is designed with one module production unit with upscaling possibility. Designed aquaponics for one modules, located near available building:

Table: 3.4.2-1

Assumption for construction and operation for one module.

- Annual production: tilapia 4.310 kg and Lettuce 636 kg. - Initial construction cost.			
Production unit	Numbers	Cost NOK each	Total cost
Tanks - fish production	6	15.661	93.968
Tanks - clarified soild removal	2	16.181	32.361
Tanks - hydroponic	7	8.375	58.625
Tanks - base additional	1	6.281	6.281
Air blower	1	6.189	6.189
Circular pump	1	10.620	10.620
Plastic pipeline hydroponic	1	46.523	46.523
Fittings, parts and other supplies	1	47.235	47.235
Operating system	1	36.250	36.250
Labour	1	70.350	70.350
Total			408.402
Assumptions for operation.			
Input cost			
Fingerlings	13.115		NOK
Fish feed	4.924		NOK
Electricity	3,35		NOK/kwh
Lettuce	4.892		NOK
Other cost	4.128		NOK
- Manager labor pr year estimated NOK 250.000 - Hired labor pr year is estimated NOK 125.000 pr. employee.			

Feasibility study shown that the minimum setup for aquaponics system are two production modules. Fixed cost is 7% of the budget and variable cost is over 90%. Efficient production unit composed of six modules.

Six modules with tilapia and lettuce production will give:

- Sales revenue 2,7 m NOK
- Variable cost 1,7 m NOK
- Fixed cost 0,2 m NOK
- Other cost 0,05 m NOK
- EBITDA 0,8 m NOK

Construction cost differ from building to building. Price for each m² for greenhouse building is estimated be NOK 4.100 included groundwork, greenhouse, floor, piping, lighting, climate control, curtains and equipment.

Twenty-year rate of depreciation on the building and pipelines and ten year on the equipment. Financial costs are set to an average interest rate of 6.5 %.

For 500 m² greenhouse building, total 2 million NOK with 70% loan funded and 30% equity the yearly repayment will be NOK 150.000 for every million NOK loan for the greenhouse and NOK 250.000 for every million NOK loan for equipment.

Norway

The Norwegian partners have modeled a deep-water culture system by upscaling the system described in chapter 2.2.1. and data described in chapter 3.3.1. Design parameters are shown in table 3.4-1. The system is designed with two modules as indicated in figure 3.4-1. This is done to increase security and flexibility of the production. The production units for fish are placed in a house separated from the green house. This is done to increase the control with the environmental parameters light and temperature.

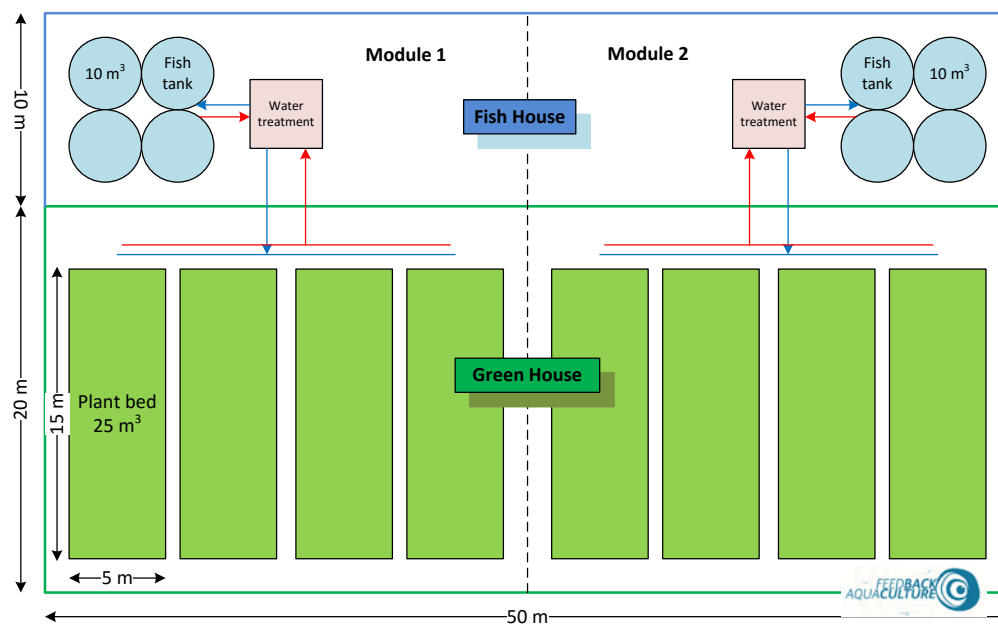


Figure 3.4-1:
Design of an up scaled aquaponics unit.

Table 3.4-1:*Production and design parameters used for the up scaled aquaponics production unit.*

Parameter	Unit	Per module	# modules	Total
SYSTEM				
Total volume whole system	m ³	150	2	300
Number of fish tanks	#	4	2	8
Total volume fish tanks	m ³	40	2	80
FISH				
Total number of fish produced	per year	18.250	2	36.500
Biomass harvest	kg per year	5.475	2	10.950
Biomass per m ³ (max)	kg/m ³	25		
Specific growth rate (SGR)	% per day	2		
Feed conversion rate (FCR)	kg feed per kg BW	1		
Total feed demand	kg per year	5.475	2	10.950
Production time ¹⁾	days	55		
PLANTS				
Average size at harvest (lettuce)	gram	100		
Numbers per m ²	#	40		
Production cycle (total)	weeks	7-8		
Time in nursery system	weeks	3		
Time in production system	weeks	4-5		
Biomass harvest ²⁾	kg per year	21.900	2	43.800

¹⁾ from 100g to 300g²⁾ Fish:Plant ratio of 1:4**Denmark**

To consider a potential upscaling of the IGFF aquaponic system and calculate a reasonable contribution margin accounting following conditions and assumptions were made:

- The IGFF test plant of 65 m² has been up-scaled to a production unit installed under a 1.000 m² greenhouse.
- Production system consists of mobile plant tables watered by 'flood and ebb' and plants grown in compost
- Fish tanks are rectangular and placed under the mobile plant tables to achieve an 'economy of space' lowering fixed investment costs on floor space
- Fish:plant output ratio is set to a biomass ratio of 1:3. This is based on the scientific study made by Licamele (2009) done on Tilapia and lettuce.
- Fish production is set to 9 MT Red Tilapia/year based on a peak biomass of 3 MT and sales every 6 week with a fish weight of 625 g
- The horticultural production is salad set to 27 MT/year sold at 200 g/head and 20 heads/m². Production cycle is set to 7 week based on a nursery system behind.
- The symbiotic effects and measurements made from modeling the IGFF production system on 1.000 m² and the production data above, have all been incorporated into the variable costs
- Sales prices for Red Tilapia are based on the price at the fishmonger, and the price of salad is what is provided to the suppliers of various CSA schemes. It is presumed that

an aquaponics production of 1.000 m² would cater for CSA, farmers markets, local restaurants etc. and hence could expect the prices applied.

- Labor time should be considered approximately one full-time person for a modern based aquaponics system like the IGFF

Contribution margin I is the surplus after the variable costs are deducted from the turnover. Contribution margin II is the surplus followed after the fixed costs are deducted. Contribution margin III is the surplus followed after the cost of loans and interest rate on investments are deducted. In the contribution margin sheet cost of loan and interest rate is considered a fixed cost and therefore merged together.

From the contribution margin accounting, it can be seen that the income before tax (Contribution margin II and III) is comparable to a well-paid skilled worker, and hence room for some fluctuations in prices or output.

The horticultural production is not surprisingly the key income generator in the aquaponics production being responsible for more than 75% of the sales income. In the same time, the aquaculture production occupies approximately 53% of the fixed costs, and therefore at first not the best production line in the greenhouse.

However, the aquaculture production contributes indirectly with 20% savings on heating in the greenhouse lowering variable costs with approximately 20.000 DKK. The CO₂ production from fish contributes to a 14% higher salad production being indirectly responsible for a sales income of approximately 260.000 DKK (Körner, Gutzman & Kledal, 2014). For more on these calculations see chapter 2.3.3. Altogether, the fish provides to contribution margin I with an income of 280.200 DKK. If one shifts this income over to the fish, they end up providing a total income value of 595.200 DKK – generating 43% of the income to the aquaponics system.

These numbers show that to actually obtain these symbiotic effects in aquaponics and have them contributing to lower the variable costs it is important that both the aqua- and horticulture sections simultaneously are being managed well.

It should be mentioned that the biomass ratio on 1:3 used in the IGFF calculation is a low ratio, and that the Norwegian partners have shown a biomass ratio of 1:4 as feasible. Applying a 1:4 ratio to the IGFF calculation would minimize the fish production and hence lower the fixed investment cost. It would however also lower the symbiotic effects (lower CO₂ and heat production), but altogether improve the overall economy.

In our calculation, we use:

Full equipment based on 6 tanks á 10 m³, Bio-filter, sedimentation, oxygen supply: DKK 1.200.000; Design, transport, installation and start-up: DKK 400.000

Prices per m²: Greenhouse in DKK: 500; Floor: 400; Curtains: 100; Heat piping: 150; Mobile plant tables: 300. Additional pricing: Lighting fixtures: 108.000; Climate control: 75.000

Ten-year rate of depreciation on the equipment. Twenty years on the greenhouse. Financial costs are set to an interest rate of 4%. To create a simpler overview of depreciation and financial costs in the contribution margin accounting, depreciation and financial costs have been merged, calculated respectively as a ten and twenty year loan with a same rate annual repayment.

Formula used $A_0 \times r / 1 - (1 + r)^{-n}$

Example: 1. Million DKK loan for the greenhouse (A), 20 years of depreciation and repayment (n), 4% interest rate (r).

$$1.000.000 \times 0.04 / 1 - 1.04^{-20} = 73.581 \text{ DKK in yearly repayment}$$

SALES ¹	DKK	TOTAL
9 MT Red Tilapia á 35.00 DKK/kg	315.000	
27 MT lettuce á 40 DKK/kg	1.080.000	1.395.000
- Variable Cost		
Feed ²	116.550	
Water ³	7.200	
Heat Energy ⁴	77.130	
Electricity:		
Light ⁵	256.590	
Pumps/oxygen etc. ⁶	68.796	526.266
= Contribution Margin I		868.734
- Fixed Cost		
Aquaculture equipment ⁷	1.633.000	
Greenhouse equipment ⁸	1.465.000	
Depreciation + financial cost ⁹		332.245
= Contribution margin II/ III		536.489

5.88 KWh/kg feed. Price 1.45 DKK/KWh.

3.4.3. Economic data analysis

Contribution margins with the system in Norway is modeled from a theoretical up-scaled system with data from production done with a small-pilot system. The system design is shown in figures 2.2-2 and table 2.2-1.

- 1 Due to the size of the aquaponic production system sales are expected to surpass normal retailers, and so cater for restaurants, farmers markets and/or different modes of CSA markets. The sales price chosen for Red Tilapia is the price found at the fishmonger. Price for salad is what various CSA pay to the farmers for Iceberg (January 2015).
- 2 12.95 DKK/kg feed and a FCR of 1,3 (9.000 kg fish X 1,3 = 11.700 kg feed)
- 3 Consumption 0.8 m³ (800 liter) per kg fish produced + plants. Price per m³: 18 DKK
- 4 0.8569 GJ/m² = 857 GJ in total. Price per GJ: 90,00 DKK
- 5 0.637 GJ/m² = 637 GJ in total. 1 GJ = 277.8 KWh. Price per KWh: 1.45 DKK
- 6 5.88 KWh/kg feed. Price 1.45 DKK/KWh.
- 7 Full Equipment based on 6 tanks á 10 m³, Bio-filter, sedimentation, oxygen supply: 1.200.000; Design, transport, installation and start-up: 400.000
- 8 Prices per m²: Greenhouse: 500; Floor: 400; Curtains: 100; Heat piping: 150; Mobile plant tables: 300. Additional pricing: Lighting fixtures: 108.000; Climate control: 75.000
- 9 A ten year rate of depreciation on the equipment. Twenty years on the greenhouse. Financial costs are set to an interest rate of 4%. To create a simpler overview of depreciation and financial costs in the contribution margin.

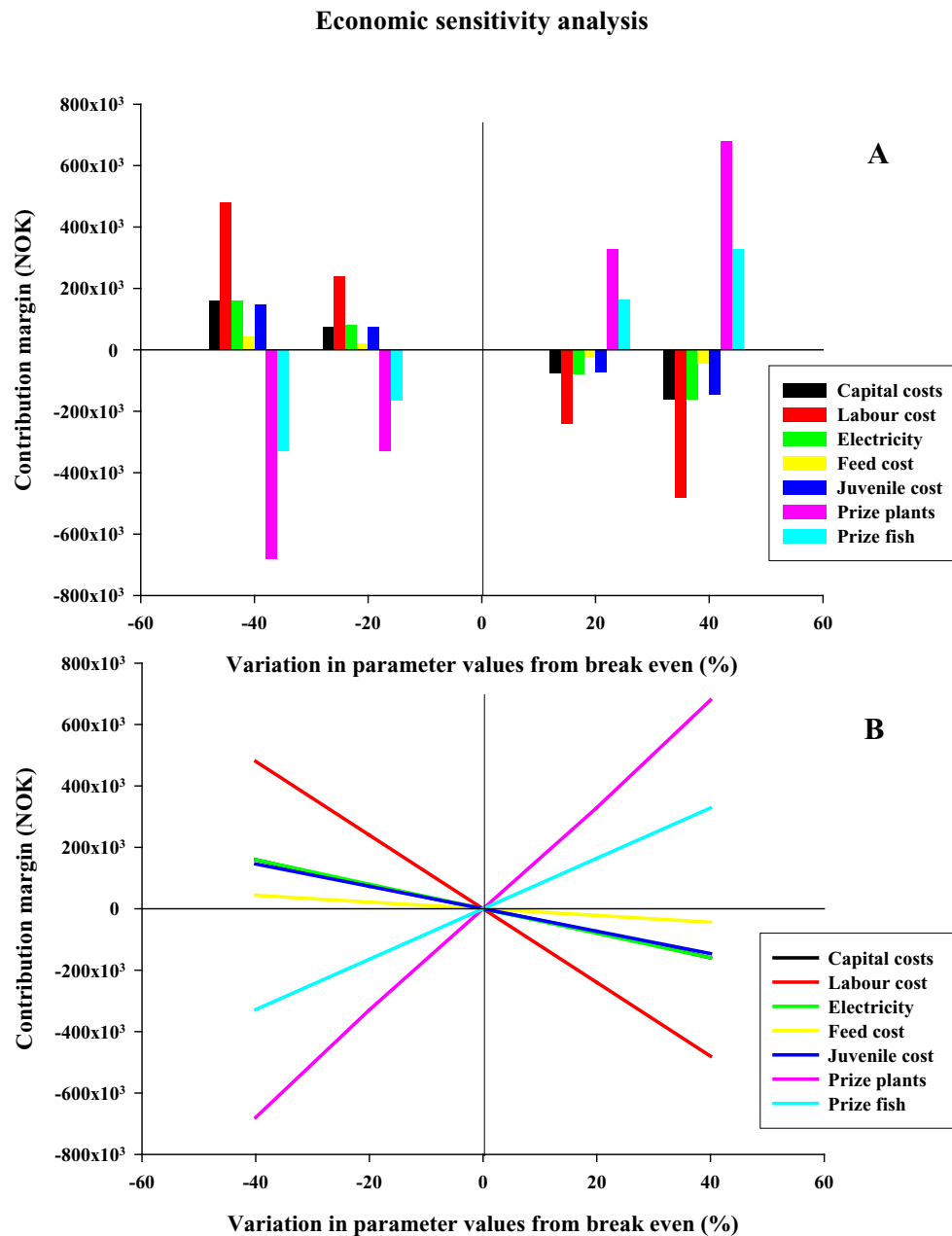


Figure 3.4-2:

Sensitivity analyses for selected cost and sales parameters. Results are shown for variation between $\pm 40\%$ from break-even prizes in model. A and B in figure present same result in two different ways for clarity (for model, see figure 3.4-3 and 3.4-4 below).

The model for the sensitivity analysis is shown in figure 3.4-3 and 3.4-4. Figure 3.4-3 shows data for a break-even budget, and figure 3.4-4 shows the example of contribution margin for an increase of 40% of sales prize of plants.

From the sensitivity analysis, it is evident that variation in labor cost and sales prize of plants is the main factors to variations in the contribution margin. Due to lower volumes of fish produced, compared to plant production, variation in fish prizes has lower impact on the contribution margin. A production ratio of 4 kg plants to 1 kg fish produced is set from our

own production in the pilot production unit. The production is based on rainbow trout and brown trout, and the production of lettuce ('Crispi'). The break-even prize for 'Crispi' is set very conservative (NOK 40 per kg). 'Crispi' has an average size of 0,1 kg and is delivered to wholesaler for NOK 10 per salad head. This gives a prize per kg of NOK 100 in local markets. Whether this can be up-scaled to 40 tons is uncertain. A fish prize of NOK 75 per kg for trout is based on a prize of NOK 25 per fish (0.3 kg). There is one producer of brown trout in Norway, and the prize they achieve is NOK 100 (gutted) per kg.

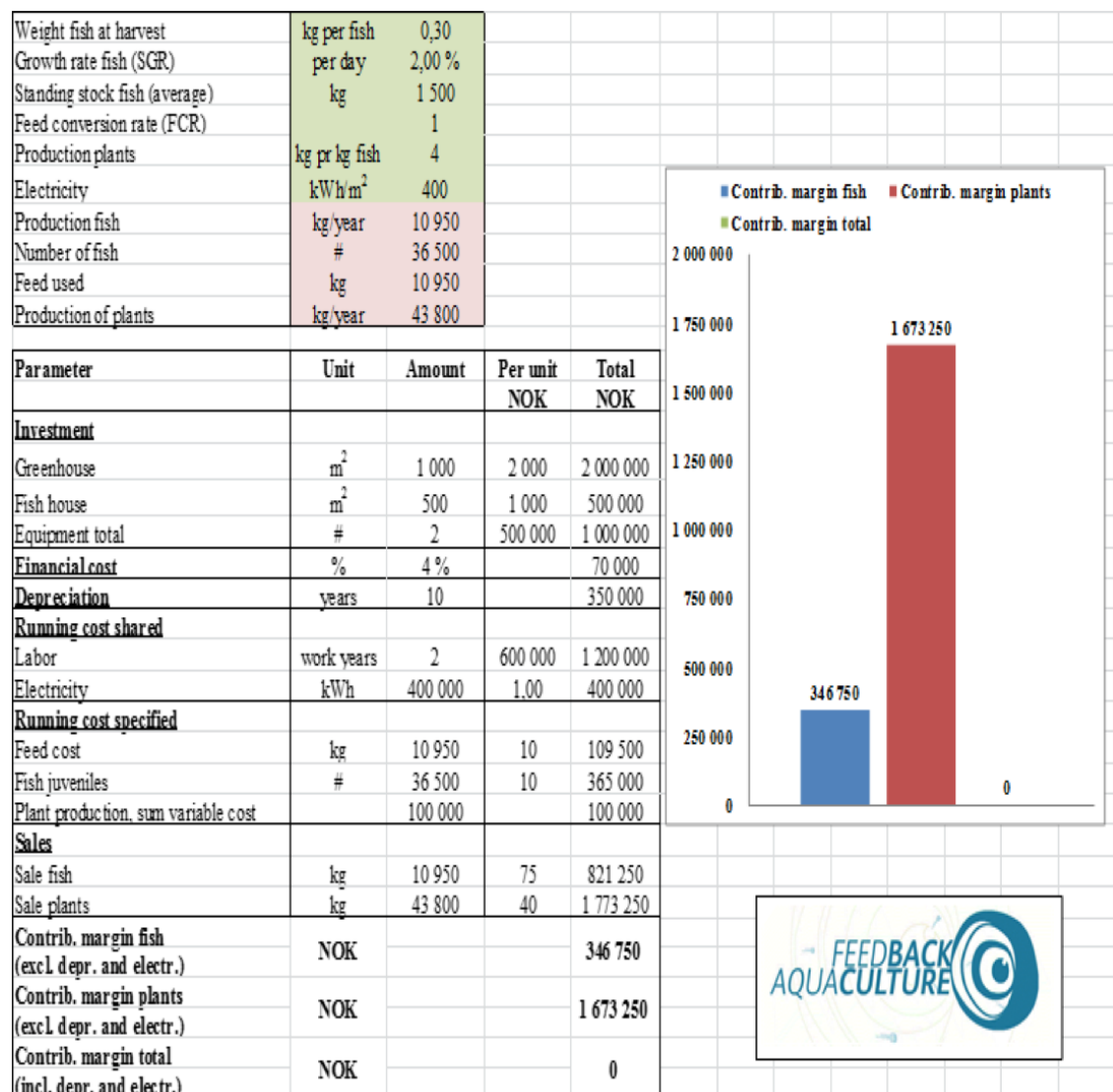


Figure 3.4-3:

A break-even production based on the model shown in figure (contribution margin total = 0).

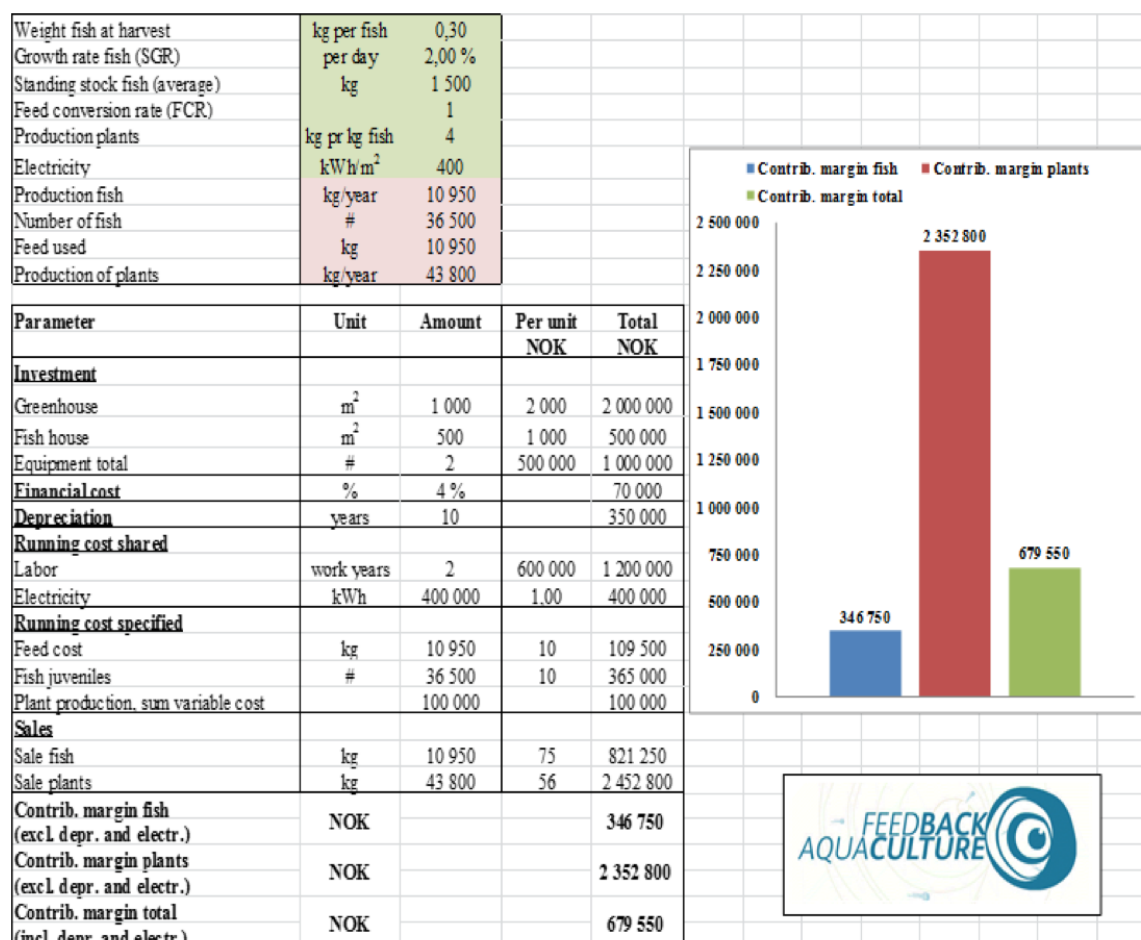


Figure 3.4-4:

Contribution margin shown for a 40% increase in sales prize for plants (contribution margin total=NOK 679,550).

3.4.4. Consumer product preferences

This section is closely related to section 3.4.1 on the consumer study made in Denmark. However, 3.4.4 contains more detailed information on consumer statements related to preferences for choice of fish as well as a more in-depth description of the consumer case in question.

A consumer study on the sales of Tilapia to a specific restaurant in Reykjavik was provided. See section 3.4.1.

Consumers prefer to have easy access to the fish market with fresh fish and “catch of the day”, and prefer filet that is easy to make good dishes. Young people today hardly know how to clean fish, ready for use in the kitchen. We also found that whole fishes, packed one of one, of about 300 gram per fish, could have a sales market.

Background

An important part for expanding the aquaponics food production is the demand side – the consumers. However, consumers are a very broad concept for many individual preferences on food, price, taste and customs as well as structural conditions laid out in terms of income, consumption patterns and options for purchasing between different distribution channels and

outlets all competing for the consumers' trade-off on time, leisure and basics needs of food. Access to modern supermarket channels requires many times the ability to provide regularly and with a 'critical mass of supply'. For a producer this would normally require substantial investments in production equipment, and hence increasing the risk that follows in the wake of such.

In aquaponics, these investment cost and associated risks would normally be larger than for other food producers within either aqua- and/or horticulture. First of all, the production dependency between the fish and plant production in aquaponics makes each production system much more vulnerable if a shot-down occurs due to a disease or a pest attack. Secondly, the lack of knowledge on the optimal biomass ratios between specific fish and plant species related to the type of production system and the choice of sustainable harvesting strategy targeting specific market and distribution system makes the investment risks even higher for an aquaponics entrepreneur if entering a more large-scale commercial market.

Due to these present obstacles limiting aquaponics producers from going large-scale explains to a high degree why the production scene are mainly characterized by a large number of small-scale DIY systems. They are typically small-scale systems, which are often based on low inputs on capital and technology investments, but high on labor time/cost requirements.

Because of these present conditions on the supply-side it was decided that a consumers study would be valuable if targeting smaller local or alternative CSA (Community Supported Agriculture) markets potential or with an easy access for local aquaponic products.

The 'KBHFF' CSA as the market study

In the heart of Copenhagen there is a CSA called 'Københavns Fødevarefællesskab' (KBHFF), which have been existing for some years now with around 1.500 members. These members were targeted for a questionnaire through their website on preferences and willingness to buy fresh fish. The size of the consumer group and the easy access for sending a questionnaire could therefore provide with a fair amount of valuable data. Fish, be it fresh or frozen, are not an option at the moment for the members of KBHFF, and therefore a potential market opportunity for a local aquaponic producer. The CSA (KBHFF) is a member-based and member-driven food cooperative. It describes itself as an alternative to the ordinary profit-driven supermarket chains focusing on offering organic and biodynamic products in season with lots of taste and quality at affordable prices (www.kbhff.dk).

To KBHFF "consumer influence" is not just the opportunity to choose between different brands and groceries. In KBHFF, the customers are members, owners and co-workers.

As a member you can buy cheap, locally produced organic fruit and vegetables every week. All members are expected to put in three hours of work in the Coop each month. This could be packing vegetables in the shop, ordering vegetables, arranging debates, fixing the website, etc.

As co-owners of KBHFF, all members have a say in the operation and development of the Coop. The members of KBHFF take all decisions regarding the products and economy, and every member has the opportunity to influence these decisions.

This structure can make decisions long-suffering, and in some cases difficult to cope with for a producer of perishable food products. Similarly, the type of consumers dedicated to CSA's can also have certain bias to 'foreign' fish like Tilapia, and have more positive preferences to a perception of 'local' varieties. In a Scandinavian context this could be fish species like Trout and Pike Perch, being one of the reasons for the fish species chosen in the NOMA project.

Anyone can become a member of KBHFF. Membership costs 100 kr. As a member of KBHFF, you can buy a bag of organic fruit and vegetables in our shops every week. You do this by pre-ordering your bag in one of the KBHFF shops. The price of one bag is 100 kr. The weekly bag

typically contains 6-8 kg of locally produced and seasonally based organic fruit and vegetables. A typical weekly bag in the autumn could be apples, salad, leeks, beets, potatoes, celery and carrots. A kilo of each. All of it fresh organic or biodynamic produce from local farms.

The rule is that you always have to pay when you pre-order. KBHFF buy from the local farmers based on the number of pre-orders they get each week, and they pay with the money they received the week before. The member can pre-order for several weeks at once, or just for the following week, and there are no obligations to buy a certain amount of bags per month. Around 5-600 bags are sold regularly per week being in the low end when summer holidays commence.

More than 60 % of the members are young families, single, couple and/or with some small children.

The questionnaire

The following questionnaire (presented as comprised version here) was designed in cooperation with the purchasing group in KBHFF for the website.

The questionnaire starts with a short introduction on the four types of fish that could be supplied (Tilapia, Red and Silver, Barramundi and Pike Perch), their expected price level and type of deliverance such as filet or a whole fish.

Pike perch have been included since they were being tried out later in the IGFF system and is regarded a luxury fish on the Danish consumer market. Difficult to grow, but more in the line with the temperature requirements in the horticulture section in comparison with Tilapia, where compromises has to be made in the whole aquaponics system. Barramundi was included in the consumer study because it could also be a potential fish for consumption, but not known to the Danish consumer market. The study was therefore to gather information that is more specific on consumer reaction if or when supplying new species.

The questionnaire was then followed by five simple questions on:

1. How often the member would like to purchase fish?
2. How many people are in the household?
3. Do the member mainly prefer the fish whole or a fillet?
4. Have the member tasted the listed four fish before?
5. Which section does the member belong to?

Results

466 members responded to the questionnaire matching closely to the number of bags sold per week. 55% said they were interested in buying fish. 12% where not sure. 13% opposed directly. 20% were not specifically pro or against, but supplied instead with explanatory comments.

Among the 55% stating they were interested in buying fish there was no specific preference between fillets or whole fish. From the few comments given it was merely a question of trade-off between consumer time preparing or not preparing a fish and the price for the fish. In other words, a supplier who can be responsive to a consumer choice on time and price will have the potential of a larger market segment. However, this would also likewise be a trade-off for the producer between the cost of a labor time for filleting and price obtained.

Among the 20% some responded positively to the option of purchasing fish, but not every week. Others were only interested if it was fillets, or if a training course could be provided on how to fillet a fish.

Some did not know the fish species presented in the questionnaire, and a few presented themselves as vegetarians/vegans.

A few replies were simply against fish.

Within KBHFF there is among the members already a fish group trying to promote fish for sale in the CSA. They informed that before X-mas 2014 they made a sales offer selling organic trout. Only 38 fish were ordered and sold. One explanation for this they said could be that the shop of KBHFF do not have any cooling facilities making it more complicated for the members to handle. The whole distribution and packaging is based on the members own volunteering and handling of the various food commodities. So structural barriers of the CSA packaging facilities could have some influence on the respondents.

The result of the questionnaire indicates that for any aquaponics producer to start up selling to a local CSA, it would be a good idea to do some promotional initiatives like pre-visiting the production, showing and informing about the products, understand the organization structure of the CSA and its decision-making.

3.4.5. Production in city compost versus organic soil

Analyses were supposed to be made comparing production results from plants grown in city compost as well as organic and biodynamic soil. The purpose was to prepare the groundwork for an organic certification of aquaponics production.

However, this Deliverable was later found unnecessary for two very specific reasons.

1. If aquaponics is already based on a production system utilizing organic/biodynamic accepted soil media, there are no problems in getting an organic certification for the horticultural produce.
2. IGFF participated in February 2014 in a two day course on Biodynamic research methods such as bio-crystallization on how to analyze the 'life quality' of plants. The leading researcher on these biodynamic methods in Denmark, Cand.agro, Ph.D. Jens-Otto Andersen, who was also responsible for the course, said however that these methods cannot stand alone. They have to be supplied anyway with classical scientific methods analyzing for the macro and micronutrients chosen already in the NOMA project.

3.4.6. Blueprint for organic production

The regulatory regime for organic fish and horticultural production in the EU is regulated by the Council Regulation (EC) No. 834/2007 whereas more detailed rules are regulated by (EC) No. 889/2008, (EC) no. 710/2009 and (EC) 834/2007.

Horticultural produce

The present regulatory regime do not have any standards or regulations for certifying organic aquaponics. The organic regulation only deals with aquaculture and horticulture production itself and separately. Each separate regulation hinders in various degrees the prospects of taking a holistic approach and work towards an organic certification for aquaponics.

For organic horticultural production current regulation 889/2008/EC, implementing regulation 834/2007/EC, contains only one element specific to greenhouse production:

art. 4

which bans hydroponic production and allows organic cultivation only in soil.

Since most aquaponic production systems are based on a soilless hydroponic technology, the plants produced under such a system cannot be certified as organic.

Aquaculture production

For organic aquaculture the production is regulated by (EC) 889/2008 and (EC) 710/2009. In par. 11. (EC) 710/2009 recirculating systems are clearly prohibited except for the specific production in hatcheries and nurseries.

Parr. 11.

Recent technical development has led to increasing use of closed recirculation systems for aquaculture production, such systems depend on external input and high energy but permit reduction of waste discharges and prevention of escapes. Due to the principle that organic production should be as close as possible to nature the use of such systems should not be allowed for organic production until further knowledge is available. Exceptional use should be possible only for the specific production situation of hatcheries and nurseries.

Since recirculating technology is the core of the aquaponics production system it is at present not possible to get an organic certification on aquaponics at all, and hence have both fish and horticultural products certified as organic.

If the plants however are grown in soil, like the IGFF system, it is possible to have the horticultural produce certified as organic – but not the fish. As a contradiction to this within the organic regulation itself the horticultural produce is allowed to be fed by conventional fish feed, similarly to an organic plant production receiving conventional manure.

Conclusion

The crux for aquaponics producers to get an organic certification lies in the future to get an acceptance of the recirculating technology within organic regulation itself.

Short-term strategies in this regard could be to:

1. View aquaponics as a farm based on a necessary harmony and biomass ratio between husbandry (the fish), and a soil-based horticultural production as the field turning waste into valuable resources and providing a food production with no discharges to the environment.
2. Work towards a specific regulation on aquaponics. This would imply allowing for a recirculating technology where a potential misuse of intensification in the fish production is already guided by the organic regulation on the number of fish allowed per m³ water, as well as a natural constraint in the required horticultural production to utilize the fish nutrients.

Paragraph 24 in the (EC) regulation 710/2009 opens up for an interpretation that such steps could be allowed. Especially the last four lines in Parr. 24 implies that national initiatives could be taken with the aim of improving the common EU regulation on organic aquaculture. However, this would require a more dedicated willingness in the organic movement to commence a process in this direction, but unfortunately this dedication and willingness does not seem to exist at present.

Parr. 24

Organic aquaculture is a relatively new field of organic production compared to organic agriculture, where long experience exists at the farm level. Given consumers' growing interest in organic aquaculture products, further growth in the conversion of aquaculture

units to organic production, is likely. This will soon lead to increased experience and technical knowledge. Moreover, planned research is expected to result in new knowledge in particular on containment systems, the need of non- organic feed ingredients, or stocking densities for certain species. New knowledge and technical development, which would lead to an improvement in organic aquaculture, should be reflected in the production rules. Therefore, provision should be made to review the present legislation with a view to modifying it where appropriate.

4. Discussion of obtained results

4.1. Discussion of results obtained in WP1: Fish

In the Icelandic trials, higher growth of tilapia was obtained at lower (80%) as compared with high (90% and 100%) recirculation levels. The optimum temperature for Tilapia is 28°C to 30°C, which is a bit too high for the plants so a compromise had to be made with the temperature maintained around 25°C. The growth of the fish was therefore not optimum for the species but good enough to make comparisons between trials and various levels of recirculation. The simplicity of the recirculation system meant that at 100% recirculation the fish did not perform as well as in 80% recirculation but that was to be expected. The 80% recirculation level gave good plant crop and the fish performed well. It is likely that by further enhancing the recirculation system used, the fish could perform as well in 90% recirculation as they did in 80% that would benefit the plant production.

In the Norwegian trials (100% recirculation), rainbow trout had far better growth than brown trout. However, both species performed well and no mortality was observed. The selection of fish species for such system will therefore depend upon the price return of the final product.

In the Danish trials (100% recirculation), stocking small tilapia fingerlings (0.3 g) into a tank prepared for end harvest level was not found suitable. Also, problems with maintaining water temperature above 20°C in the system have been experienced during winter and call for modification of the system, with heating pipes controlled by thermostats installed at the fish tanks for securing a better and stable growth rate of the fish.

4.2. Discussion of results obtained in WP2: Plants

4.2.1. Discussion of results from Iceland

The plant types tested in the Icelandic trials performed very differently. Of unknown reasons, the Mizuna performed very poorly. The study indicates that growth of tilapia is greater at a lower recirculation level (80%) compared to higher levels of recirculation (90% and 100%).

Lettuce growth was good at an 80% recirculation level and similar at 100% recirculation, but for some reason, suboptimal at 90% recirculation. This may be explained by slightly lower levels of nitrate and phosphate at 90% recirculation. Mizuna growth was higher at 90% and 100% recirculation, compared to 80% recirculation. For some reason, the growth of mizuna was greatest at a 90% recirculation level. Overall, mizuna growth was poor which indicates that it might be difficult to grow in aquaponic systems.

The study indicates that the nutrient composition of fish farm effluence can be favorable for the growth of hydroponic vegetables. Growth in biofiltered effluence was equal to or greater than growth in a standard hydroponic solution. There was no consistent difference in plant growth when using different growth media, pumice or hydroton.

4.2.2. Discussion of results from Norway

Effluent content in the wastewater, is dependent on what fish feed the system has as input (figure 3.2-9). Different feed ingredients gives different nutrient amount for plant growth, content of proteins (nitrogen compounds), macro- and micronutrients. Different fish species requires, different water quality and legislation may affect maximum allowed fish densities, and all these parameters can influence plant growth.

The plant studies in Norway showed clearly the effect of having a mature and balanced system. Under the first study, the plants were not growing so well, due to too little fish feed given to the fingerlings to maintain a normal plant growth. There were clearly symptoms of lack of nutrients at the plant leaves. Lack of nitrogen gave the plants very yellow leaves (figure 3.2-5) with very little amount of chlorophyll to have the photosynthesis going for producing sugar and energy, and obtain normal growth. Therefore, the plants were smaller than the plants in the hydroponics.

The nutrient deficiencies and reduced growth observed in trial 1, 2014 can be explained by low level of available nutrients due to low density of fish in the system. All green plants needs to have an amount of nitrogen to develop chloroplasts and chlorophyll that makes oxygen, sugar and energy for the plant. Red lettuce varieties have also chlorophyll, but in a lower content, and for that reason they growth a little bit slower than the green plant varieties, and nutrient deficiency is not so visible (figure 3.2-3, 3.2-4). In trial 2 (2014), it was observed that elderly plants with good root system, began to set out new roots from the end of the stem of the plants when moving over to aquaponics water from hydroponics water (figure 3.2-7). This might be to manage the low nutrients content in the aquaponics water.

In the study performed in spring 2015 (trial 4) with lettuce 'Crispy', the plants grew very well, and a state of balance was obtained in the system for both fish feed and plant biomass. During trial 4 (2015), there were always 672 plants in the system, and they were different in plant size and age. Elder/larger plants takes up more nutrients than young/small plants, and they have different requirement of nutrients amounts. Plant leaves did not have any signs of nutrient deficiencies, and they had a total production time of 7-8 weeks from seed to sales product. It looks like the lettuce variety 'Crispi' is a success in a trout aquaponics.

The Norwegian fish feed for cold-water fish, is higher in protein content than for feed for tilapia. In fish feed for trout, iron (Fe) is added. The plants therefore gets quite good quality of nutrients in the water. Once the water has been into the plant beds, it get's filtered, and the water can be returned to the fish tank, and cycle repeated repeatedly, with an exchange rate of about 350 l/min. The water quality is then very steady in the entire system. To run the production system all year around will be expensive in energy for heating or chilling of the water and use of artificial grow light in autumn and winter. However - 60 % of the income can come from the plant-side in an aquaponic system.

Our study shows that lettuce (*Lactuca sativa*) is a very good specie to produce in trout aquaponics systems and its water quality, because of a high growth rate (figure 3.2-10) and high popularity by consumers (stakeholder's observations). The prize is high for good quality and single packed heads (NOK 10 to producer). Good lettuce varieties are *green oak*, *green cos*, *crispi* and *butterhead*, but also red varieties thrives in trout aquaponics, we have experienced though our trials.

Each grower need to see what market there is available for his production site and do some marketing research before choosing which crops the site should produce.



Figure 4.2.2-1a:

Red variety of lettuce in trout aquaponics at Bioforsk Landvik (pictures taken 22nd of May 2015).

Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO.

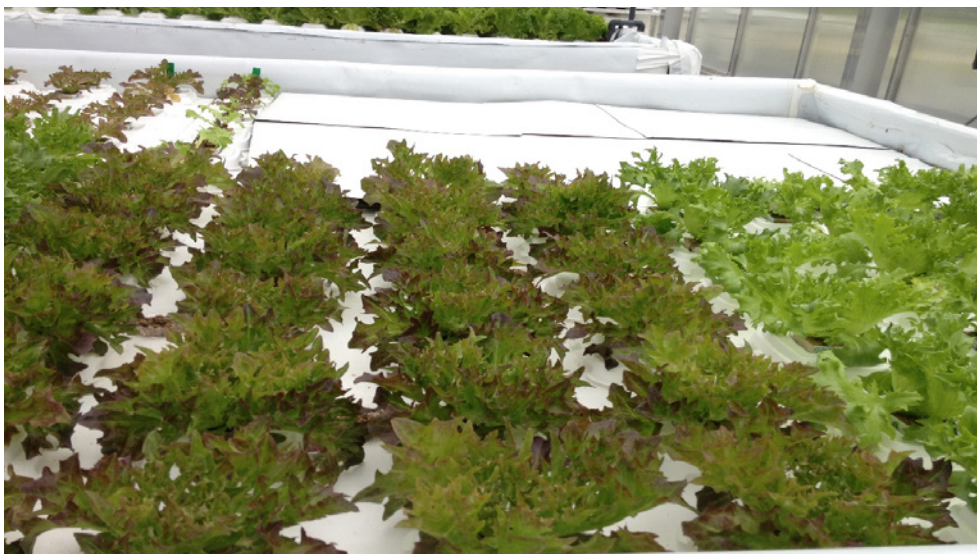


Figure 4.2.2-1b:

Red variety of lettuce in trout aquaponics at Bioforsk Landvik (pictures taken 22nd of May 2015).

Photo: Siv Lene Gangenes Skar, Bioforsk/NIBIO.

The quality of the lettuce was very good with a remarkable crispiness and feedback from stakeholders and consumers are excellent.

4.2.3. Discussion of results from Denmark

Fish biomass is at present being built up for correct scientific biomass studies on the IGFF system. So far a great variety of herbs, tomatoes and salads are being tested both in the production as well as sold to consumers at the KBHFF (CSA) and a greengrocer shop. Plants with growth periods for more than 8 weeks have shown signs of deficits on macro nutrients such as potassium and nitrate due to the low level in the fish biomass and hence feed level. Consumer reactions as well as the greengrocer owner are overwhelmingly positive. A response that is repeated over and over is, that the plants are 'alive'. Consumers say they have the

plants for a long time. Selling the plants in pots and soil combined with a dense root session seems to be a very strong platform for entering markets with horticultural products based on aquaponics.

4.3. Discussion of results obtained in WP3: Technology

As a simple and cost effective system the technology used in the Icelandic system worked well. The electricity use was very low. The back-flushing of the pumice filter needs to be improved and made automatic.

The integration of well-known technologies applied in both commercial and industrial aqua- and horticulture as well as ‘separating’ plant production via mobile tables for plants in soil and pots has so far proven very successful for optimal water treatment. For a commercial oriented production where fingerlings are brought in on a continuous basis it is recommended to have smaller tank sizes with heating pipes inside to secure maximum feed uptake and as well as growth rate.

Experience and results from Norway show that it is possible to operate the systems and produce first class fish and plants (salad) over long time (so far more than 6 month) with 100% recirculation without having significant negative effects from accumulating substances in the breeding water. In the test period, the system produced 4.3 times as much plants as fish measured as wet weight. There is a potential of producing even more plants by utilizing the nutrients in water and sludge better. Based on the results from the project, important water treatment units to be included are:

- Particle removal. Filtration is required to remove finer particles.
- Aeration, oxygenation and CO₂-stripping. Diffused aeration directly in fish tanks and plant tanks, and low plastic column aerators for recirculating water.
- Biofiltration. Different processes and media can be used. In our system moving bed media (Kaldnes) and a bead-filter were used. It is important to have automatic back-flushing of filters to prevent operational problems.
- pH-adjustment and alkalization. A system for pH-adjustment and alkalization must be included. The best solution is to use an automatic dosing system controlled by in-line pH-measurement. By dosing CaCO₃-slurry, there is little risk of overdosing.

Solid produced from solid separation units (swirl separators and bead-filter) has to be stored, treated, concentrated and used (see chapter 3.3.2).

4.4. Discussion and conclusion of results obtained in WP4: Business Designs

A major challenge in up scaling of aquaponics production is the larger amount of risk an entrepreneur will endure. This goes in regards to the dependency challenge as well as the higher degree of fixed costs, which can only be recaptured in lower variable costs through a well-managed production in both the aqua and horticulture section. These challenges have all been addressed in the NOMA project, and the positive results could support a move towards small-scale commercial productions at first in the Nordic countries.

Both the Norwegian as well as the Danish system showed positive returns on the income if up scaling their various systems to a 1.000 m² production area. A production of this size cannot deliver the ‘critical mass of supply’ necessary to cater for modern supermarkets. Instead, local

markets or 'alternative' CSA's within an urban proximity has to be targeted to secure higher price premiums.

A consumer study was therefore made in relation to a CSA focusing on their type of preferences concerning choice of fish, whole fish or fillet, price willingness etc. Results showed, when catering for these local oriented CSA's structural barriers in the supply chain is an important factor that has to be addressed. This goes especially in regards to requirements of cooling a perishable product like fish in terms packaging and storing facilities, which often would be too expensive for the members of a CSA. Hence, the cost on pre-packaging, deliverance and storage has to be considered if targeting both local markets and more alternative distribution channels like various types of CSA's.

Iceland consumer study on the sale of Tilapia was done by restaurants and with discussions to chefs. Matorka Tilapia has been on several restaurants menu for years, not always the whole year, but some period every year. Customers are consciously about of the fish origin and the water quality, compared to the pond raised fish. In general, Matorka Tilapia has been a success and has good customer rating, according to owner of one of popular restaurant in Reykjavik.

5. Conclusion

5.1. *Fish experiments*

The study in Iceland indicates that growth rates of Tilapia are higher at a lower recirculation level (80%) as compared to higher levels of recirculation (90% and 100%). The results furthermore indicate that re-used effluent water from fish farming operations, can be used directly for cultivation of different plant species, using local material in a simple and cost effective system for filtration of effluent water from the fish. This may be an interesting option for smaller producers of fish in land-based aquaculture, especially for producers with access to geothermal water for maintaining the appropriate and stable temperatures for the fish as well as the plants selected.

The system applied in Norway was 100% recirculated, i.e. there is no effluent from the system, and water is added only to replace evaporation and flushing of particles from filters. Recommendations for water quality should be followed (recommended levels for recirculation aquaculture), to support good growth and survival of the fish, including efficient particle filtration, monitoring pH. Also, maintain pH close to 7.0 and keep the fish density below 25 kg/m³ if only aeration is used and no oxygenation of the water. Measure water quality parameters from nitrification once every week (TAN, NO₂, NO₃), and monitor chloride levels for maintaining at 100 mg/l. Rainbow trout showed significantly higher growth rates than brown trout, indicating the importance of selecting the appropriate fish species for such systems.

The results from Denmark showed that in a recirculating system it is important to have fish tanks applicable to the size and volume of the fingerlings inserted to secure maximum feed intake and optimal growth rate. In this regard heating pipes within the tanks to control a regular and optimal fish temperature is also recommended. Selecting a certain air temperature in the greenhouse may not be sufficient for maintaining the appropriate water temperature during cold winter months and/or warm summer months, thereby compromising fish growth and wellbeing. Heating – and cooling pipes within the tanks to control a regular and optimal temperature of the culture water is generally not recommended due to problems with cleaning, but can in some cases be a solution for smaller systems.

5.2. *Plant experiments*

The Norwegian studies indicates that the nutrient composition of fish farm effluence can be favorable for the growth of hydroponic vegetables. Studies show that when the aquaponics system has matured over some time and when balancing fish and plant production, the quality of lettuce is very good (figure 3.2-12). Other crops are also suitable for cold-water based aquaponics like parsley, Swiss chard, some eatable flowers (nasturtium, borage herb, etc.), herbs and several lettuce varieties. Since the plant production do not add anything but good

practice for fish welfare, several plant species can be grown at the same time due to what your market and costumers wants.

Icelandic studies showed that lettuce growth was good at an 80% recirculation level and similar at 100% recirculation, but for some reason, suboptimal at 90% recirculation. This may be explained by slightly lower levels of nitrate and phosphate at 90% recirculation. Mizuna growth was higher at 90% and 100% recirculation, compared to 80% recirculation. For some reason, the growth of mizuna was greatest at a 90% recirculation level. Overall, mizuna growth was poor which indicates that it might be difficult to grow in Icelandic aquaponic systems. Growth in biofiltered effluence was equal to or greater than growth in a standard hydroponic solution.

Applying soil to an aquaponics system has proven very valuable in terms producing healthy plants and the ability to supplement additional nutrient packages without compromising the health of the fish.

5.3. Technical experiments

There was no consistent difference in plant growth when using different growth media, pumice or Hydroton. The recirculation system used can be and should be developed further to suit better both fish and plants in an aquaponics production. Introducing well-known industrial technologies applied in commercial aqua- and horticulture production, combined with plants, produced on mobile tables in pots with soil, has proven valuable in terms of:

1) excellent water treatment, 2) free from sludge deposits on plant roots and tank floors and 3) sedimentation can be composted and reused in the plant production leaving zero discharges to the water environment.

The technology used in the Icelandic system was a simple and cost effective one and proved to work well. Well-known technologies applied in both commercial and industrial aqua- and horticulture were integrated and 'separating' plant production via mobile tables for plants in soil and pots proved successful for optimal water treatment. For a commercial aquaculture production where fingerlings are brought in on a continuous basis, it is recommended to have smaller tank sizes with heating pipes inside to secure maximum feed uptake and growth of the fish.

Experience and results from Norway show that it is possible to operate the systems and produce first class fish and plants (salad) over long time (so far more than 6 month) with 100% recirculation without having significant negative effects from accumulating substances in the breeding water. The solid separation technology performed well, maintaining suspended solids (SS) and turbidity (FTU) in the range of 3-13 mg/l and 2-5 FTU, respectively. In the test period, the system produced 4.3 times as much plants as fish measured as wet weight. There is a potential of producing even more plants by utilizing the nutrients in water and sludge better.

5.4. Business designs

Results from the experiments carried out at the aquaculture farm of Matorka Ltd. In Iceland indicate that re-used effluent water from fish farming operations can be used directly (without 100% recirculation) for cultivation of different plant species, using local material in a simple and cost effective system for filtration of the water. Production of vegetables or fruits in partially recirculated and nutrient rich effluents from aquaculture operations may therefore be an interesting option for smaller producers of fish in land-based aquaculture in Iceland. This may be of particular interest for operations with access to geothermal water resources allowing the production of a broader spectrum of plants, even exotics plant commonly produced only at lower latitudes.

The positive results from the NOMA project could support at first a move towards small-scale commercial productions in the Nordic countries. Both the Norwegian as well as the Danish system showed positive returns on the income if upscaling their various systems to a 1.000 m² production area. A production of this size cannot deliver the ‘critical mass of supply’ necessary to cater for modern supermarkets. Instead local markets or ‘alternative’ CSA’s within an urban proximity has to be targeted for securing a higher price premium. However, structural barriers within a supply chain of CSA’s lacking cooling facilities has to be considered carefully in terms keeping food safety regulations for a perishable product such as fish.

5.5. Web sites with more information about aquaponics

www.aquaponics.is

www.aquaponic.com.au

www.aquaponics.net.au

www.aquaponicssystems.net/wp-content/uploads/2012/09/Aquaponics-System.jpg

www.crainsdetroit.com/mobile/article/20141210/BLOG009/141219978/hope-center-to-build-aquaponics-farm-to-grow-produce-raise-fish-to?X-IgnoreUserAgent=1

www.dryhydroponics.com

www.examiner.com/article/a-brief-introduction-to-aquaponics

www.fao.org/3/a-i4021e/i4021e01.pdf

www.hamzasreef.com/Contents/Calculators/FreeAmmonia.php

www.hydroponics.com.au/issue-101-aquaponics-revisited/

<http://ottiliashave.dk/aquaponics/>

<http://plantelaboratoriet.dk/>

www.theaquaponicsdoctors.com

www.urbanfarmers.com/technology/aquaponics/

<http://www.japan-aquaponics.com/cow-powered-commercial-aquaponics.html>

<http://diyaquaponic2015.info/2014/09/#forward>

... and there are many more in the internet.

Appendix no. 1

CONSUMER REPORT

On preferences for fish in a Danish CSA



April 2015

Background:

An important part for expanding the aquaponic food production is the demand side – the consumers. However, consumers are a very broad concept for many individual preferences on food, price, taste and customs as well as structural conditions laid out in terms of income, consumption patterns and options for purchasing between different distribution channels and outlets all competing for the consumers' trade-off on time, leisure and basics needs of food.

Access to modern supermarket channels requires many times the ability to provide regularly and with a 'critical mass of supply'. For a producer this would normally require substantial investments in production equipment, and hence increasing the risk that follows in the wake of such.

In aquaponics these investment cost and associated risks would normally be larger than for other food producers within either aqua- and/or horticulture. First of all, the production dependency between the fish and plant production in aquaponics makes each production system much more vulnerable if a shot-down occurs due to a disease or a pest attack. Secondly, the lack of knowledge on the optimal biomass ratios between specific fish and plant species related to the type of production system and the choice of sustainable harvesting strategy targeting specific market and distribution system makes the investment risks even higher for an aquaponic entrepreneur if entering a more large-scale commercial market.

Due to these present obstacles limiting aquaponic producers from going large-scale explains to a high degree why the production scene are mainly characterized by a large number of small-scale DIY systems. Typically small-scale systems, which are often based on low inputs on capital and technology investments, but high on labor time/cost requirements.

Because of these present conditions on the supply-side it was decided that a consumers study would be valuable if targeting smaller local or alternative CSA (Community Supported Agriculture) markets potential or with an easy access for local aquaponic products.

The 'KBHFF' CSA as the market study

In the heart of Copenhagen there is a CSA called 'Københavns Fødevarefællesskab' (KBHFF), which have been existing for some years now with around 1.500 members. These members were targeted for a questionnaire through their website on preferences and willingness to buy fresh fish. The size of the consumer group and the easy access for sending a questionnaire could therefore provide with a fair amount of valuable data. Fish, be it fresh or frozen, are not an option at the moment for the members of KBHFF, and therefore a potential market opportunity for a local aquaponic producer.

The CSA (KBHFF) is a member-based and member-driven food cooperative. It describes itself as an alternative to the ordinary profit-driven supermarket chains focusing on offering organic and biodynamic products in season with lots of taste and quality at affordable prices (www.kbhff.dk).

To KBHFF "consumer influence" is not just the opportunity to choose between different brands and groceries. In KBHFF, the customers are members, owners and co-workers.

As a member you can buy cheap, locally produced organic fruit and vegetables every week. All members are expected to put in three hours of work in the Coop each month. This could be packing vegetables in the shop, ordering vegetables, arranging debates, fixing the website, etc.

As co-owners of KBHFF, all members have a say in the operation and development of the Coop. All decisions regarding the products and economy are taken by the members of KBHFF, and every member has the opportunity to influence these decisions.

This structure can make decisions long-suffering, and in some cases difficult to cope with for a producer of perishable food products. Similarly, the type of consumers dedicated to CSA's can also have certain bias to 'foreign' fish like Tilapia, and have more positive preferences to a perception of 'local' varieties. In a Scandinavian context this could be fish species like Trout and Pike Perch, being one of the reasons for the fish species chosen in the NOMA project.

Anyone can become a member of KBHFF. Membership costs 100 kr. As a member of KBHFF, you can buy a bag of organic fruit and vegetables in our shops every week. You do this by pre-ordering your bag in one of the KBHFF shops. The price of one bag is 100 kr. The weekly bag typically contains 6-8 kg of locally produced and seasonally based organic fruit and vegetables.

A typical weekly bag in the autumn could be apples, salad, leeks, beets, potatoes, celery and carrots. A kilo of each. All of it fresh organic or biodynamic produce from local farms.

The rule is that you always have to pay when you pre-order. KBHFF buy from the local farmers based on the number of pre-orders they get each week, and they pay with the money they received the week before. The member can pre-order for several weeks at once, or just for the following week, and there are no obligations to buy a certain amount of bags per month.

Around 5-600 bags are sold regularly per week being in the low end when summer holidays commence.

The questionnaire

To get as many members to answer, and in the same time get a valuable overview of a

willingness to purchase fresh fish from this specific CSA market, the following questionnaire (placed in Appendix) was designed in cooperation with the purchasing group in KBHFF for the website.

The questionnaire starts with a short introduction on the four types of fish that could be supplied (Tilapia, Red and Silver, Baramundi, and Pike Perch), their expected price level and type of deliverance such as filet or a whole fish.

The questionnaire is then followed by five simple questions on:

1. How often the member would like to purchase fish
2. How many people are in the household
3. Do the member mainly prefer the fish whole or filet
4. Have the member tasted the listed four fish before
5. Which section does the member belong to

Results

466 responded to the questionnaire matching closely to the number of bags sold per week.

55% said they were interested in buying fish

12% where not sure

13% opposed directly

20% were not specifically pro or against, but supplied instead with explanatory comments.

Among the 20% some responded positively to the option of purchasing fish, but not every week. Others were only interested if it was fillets, or if a course could be provided on how to fillet a fish.

Some did not know the fish species presented in the questionnaire, and a few presented themselves as vegetarians/vegans.

A few replies were simply against fish.

Within KBHFF there is among the members already a fish group trying to promote fish for sale in the CSA. They informed that before X-mas 2014 they made a sales offer selling organic trout. Only 38 fish were ordered and sold. One explanation for this they said could be that the shop of KBHFF do not have any cooling facilities making it more complicated for the members to handle. The whole distribution and packaging is based on the members own volunteering and handling of the various food commodities. So structural barriers of the CSA packaging facilities could have some influence on the respondents.

A new questionnaire to the members of KBHFF is planned to be made, but targeting one of the high-end sections of the CSA. Likewise, a pre-visit tour to the IGFF aquaponic test plant has been arranged with this section for both learning about the production system, seeing the fish and horticultural produce as well as making the visit a purchasing tour of the various herbs produced.

The result of the questionnaire indicates that for any aquaponic producer to start up selling to a local CSA, it would be a good idea to do some promotional initiatives like pre-visiting the production, showing and informing about the products, understand the organization structure of the CSA and its decision making.

APPENDIX:

Spørgeskemaundersøgelse blandt medlemmerne af KBHFF: Interesse for køb af fersk økologiske fisk opdrættet i Danmark

Spørgeundersøgelsen introducerer kort de fire fisketyper, som vil kunne tilbydes, forventede prisniveauer samt leveringsvilkår. Herefter følger blot fem spørgsmål, som kan besvares med et kryds omkring præferencer for køb og type af fisk:

Type af fisk:

Barramundi er en saltvandsfisk rig på omega-3, proteiner, vitaminer og mineraler. Smagen er mild og en smule sød. Konsistensen er som andre hvidfisk, og kan tilberedes ved stegning, koges eller grilles.

Tilapia (rød) er en ferskvandsfisk og meget smuk når den serveres som hel fisk grillet eller stegt. Kødet inde i er en hvid fisk med en mild smag.

Tilapia (sølv) er en ferskvandsfisk. Kødet er en hvid fisk, mild i smagen og derfor anvendelig til mange retter, hvor saucen (eksempelvis tomat, karry, kokos etc.) bliver den primære smagsfremhæver. Meget populær i USA pga. sine mange anvendelsesmuligheder bl.a. i børnefamilier.

Sandart er en luksus ferskvandsfisk og meget kendt i Tyskland og Central Europa på restauranter. Det er en hvid fisk og anses for en af de bedste spisefisk fra ferskvand. Den hører til Aborre familien, og vil i smagen ligge tæt herpå.

Priser:

FISKE TYPE	HEL	FILET	PRIS
Barramundi	X		115 kr./kg
Tilapia (rød)	X		45 kr. for 600 gram
Tilapia (sølv)		X	60 kr./kg
Sandart	X	X	90 kr./kg hel fisk 60 kr. for filet á 600 gram

Leveringsvilkår:

Fiskene er præ-pakket og klar til individuel levering. Medlemmerne skal derfor IKKE sortere og pakke fisk.

SPØRGSMÅL OG AFKRYDSNING:

1. Hvor tit vil du gerne kunne købe friske fisk i KBHFF? Sæt kryds (X)

En gang om ugen hver 14 dag En gang om måneden Andet
☐ ☐ ☐ ☐

Hvis andet, skriv dit ønske _____

2. Hvor mange personer findes der i husholdningen? Sæt kryds (X)

1 ☐; 2 ☐; 3 ☐; 4 ☐; Flere ☐

3. Foretrækker du overvejende fileteret eller hel fisk? Sæt kryds (X)

Fileteret ☐ Hel ☐

4. Har du prøvet at spise nogle af de fire ovennævnte fiske typer før? Sæt kryds (X)

Ja ☐ Nej ☐

Hvis kryds i ja, skriv hvilke (navn/avnene)

a) Kunne du tænke dig at prøve ovennævnte fisk selvom de er ukendte for dig?

Ja ☐ Nej ☐

5. Hvilken afdeling hører du til? _____

Appendix no. 2

A) Data from Norwegian Experiment 16th of January- 13th of March

Date	WATER QUALITY IN TROUT AQUAPONICS									Input/Output			
	TAN-N	NO ₂ -N	NO ₃ -N	PO ₄ -P	Cl-	Ledn. evne	Turb.	Temp.	pH	CaCO ₃	Water in	Feed	Sludge
	mg/l	mg/l	mg/l	mg/l	mg/l	mS/cm		°C		gram	liter	gram	liter
16.jan	0.075	0.201	90.8	2.71	118	1380		16.6	7	500		720	15
17.jan								16.5	7	500	285	720	16.9
18.jan	0.073	0.201	93.6	2.84	119	1410		16.7	6.99	500	33.6	720	23.7
19.jan								16.3	6.97	500	33.8	720	23.4
20.jan								16.1	7.02	500	16.6	780	21
21.jan	0.083	0.223	101.2	2.94	121	1450		16.3	7.01	500	15.6	780	11.5
22.jan								16	6.97	500	64.2	780	15.6
23.jan	0.122	0.237	98.8	2.97	117	1520		15.6	6.96	500	74.4	780	17.4
24.jan								15.5	6.96	250	660	560	19
25.jan								16.1	6.86	500	21	560	15.4
26.jan	0.099	0.142		2.95	110	1430		16.7	6.97	500	32	560	21.2
27.jan			80					16.7	6.93	500	92.3	560	16.5
28.jan								16.1	6.95	500	142.2	710	22
29.jan	0.099	0.134	50.4	3.37	104			16.3	6.99	500	205.9	710	16.8
30.jan	0.06	0.139	58.3	3.05	107	1460		16.5	6.92	500	90.1	710	21.6
31.jan								16.1	7.01	500	0	700	15.8
01.feb								16.4	6.96	500	1306.6	700	16.8
02.feb	0.098	0.168	43	2.98	94.6	1350		16.5	6.94	500	0	700	22
03.feb								16.4	6.89	500	0	700	16.5
04.feb								16.2	6.93	0	142.3	700	16.2
05.feb								16.1	6.9	0	56.2	700	15.72
06.feb	0.114	0.178	98.8	3.13	99.1	1410		16.7	6.95	500	32.5	700	16
07.feb								15.7	6.97	0	94.1	700	10
08.feb								16.5	6.96	500	17	700	10.34
09.feb	0.11	0.188	104.8	3.47	96.6	1450		16.6	6.97	500	61.2	600	19.8
10.feb								15.9	6.93	500	0.3	600	16.6
11.feb								16.9	6.9	500	0	600	33.1
12.feb								16	6.9	500	115	600	16.6
13.feb	0.1	0.151	123.6	3.54	94.8	1440	5.69	16.5	6.96	500	137.6	600	17.2
14.feb								16.5	6.92	500	120.9	600	20.9
15.feb								16.5	5.91	500	32.4	600	16.9
16.feb	0.106	0.168	109.6	3.55	94.7	1520	3.89	16.4	7	0	29.4	780	24.3
17.feb								16.4	7.04	500	0.1	780	16.7
18.feb						1530	3.28	15.9	6.98	0	29.9	780	16
19.feb								15.1	7	500	0	780	16.2
20.feb	0.103	0.204	118	4.4	96.8	1610	3.24	16.6	6.99	500	84.8	780	21.1
21.feb								16.1	6.95	500	85.3	780	14.22
22.feb								17.1	6.91	500	27.9	780	15.7
23.feb	0.164	0.211	117.1		93.4	1610	3.25	16.8	6.94	500	56.6	780	17
24.feb								14.4	6.93	500	7	780	16.9
25.feb				3.96				16.5	6.87	500	23.6	780	15.7
26.feb								16.2	6.94	500	2.1	780	9.1
27.feb	0.085	0.196	160.4	4.17	96.8	1700	5.04	17	6.88	500	2	700	14.3
28.feb								16.2	6.93	500	0.9	700	12

01.mar								16.9	6.9	500	0	700	16.7
02.mar	0.084	0.13	143.2	4.3	95.1	1710	4.05	15.2	6.89	500	13.5	700	23
03.mar								16.4	6.86	700	3.7	700	17
04.mar						1740	4.1	16.1	6.88	700	1.8	700	16.7
05.mar								15.1	6.87	700	0	700	17.4
06.mar	0.062	0.147	66.5	4.1	81.9	1710	5.06	16.1	6.87	700	28.5	800	8.9
07.mar								16.7	6.83	700	22.1	800	12
08.mar								17.7	6.85	700	37.9	800	13.3
09.mar	0.109	0.178	124.4	5.1	79.6	1750	3.21	16.3	6.84	700	17.1	800	18.6
10.mar								16.4	6.88	700	22	800	25.4
11.mar								16.6	6.92	700	15.2	800	27.6
12.mar						1740	4.54	15.7	6.85	700	25.9	800	27.7
13.mar	0.089	0.185	128.4	5.27	91.2	1790	3	16.5	6.9	700	7.4	800	15.6

B) Data from Norwegian Experiment 16th of January- 13th of March

	Production											Input		
Date	Fish				Plants				Sludge			Feed		
	Biomass in tanks	Out	N	P	Biomass in beds	Out	N	P	Produced	N	P	Added	N	P
	g	g	g	g	g	g	g	g	litres	g	g	g	g	g
30.jan	42 044				8 349									
06.feb		6 940	211	15		10 252	17	2	124.6	59	14	4 910	355	65
13.feb		7 516	228	16		13 616	22	3	122.4	26	10	4 500	325	59
20.feb		4 702	143	10		16 482	27	4	128.2	45	11	4 920	355	65
27.feb		8 538	259	18		11 020	18	3	109.7	100	29	5 460	394	72
06.mar		477	14	1		9 526	15	2	117.1	57	16	4 900	354	65
13.mar	34 718				26 139	10 900	18	2	133.5	65	18	5 600	404	74
SUM		28 173				71 796								
Production	20 847		634	45	89 586		145	20	735.5	351	97	30 290	2187	400

Date	Sludge	
	N mg/l	P mg/l
06.feb	470	110
13.feb	210	80
20.feb	350	87
27.feb	910	260
06.mar	485	134
13.mar	485	134

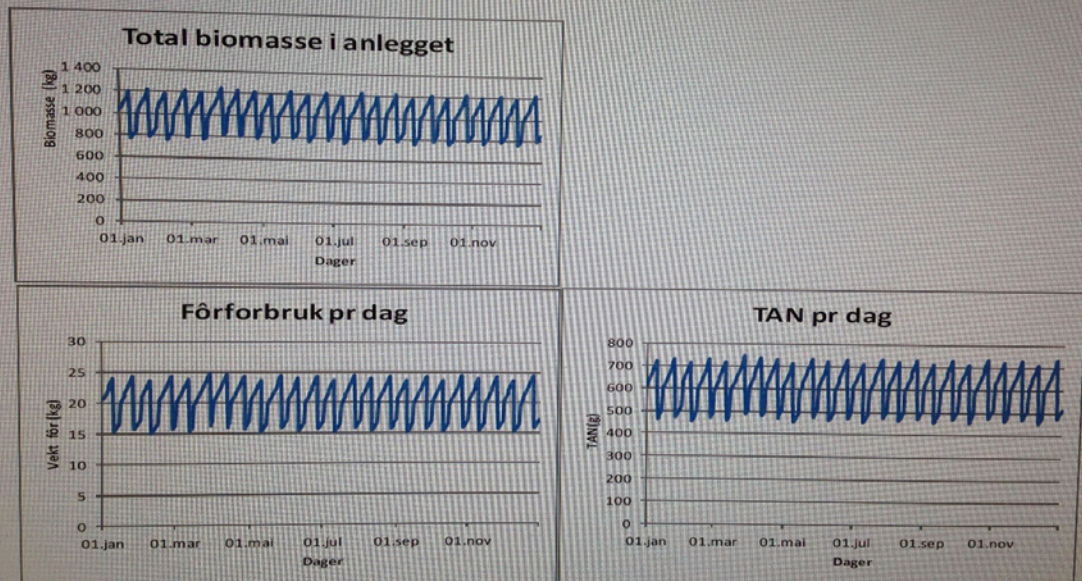
N fish (%TS)	10.13 %
P fish (%TS)	0.72 %
% TS fish	30.00 %
N plants (%TS)	4.84 %
P plants (%TS)	0.68 %
% TS plants	3.34 %
N feed (%TS)	7.60 %
P feed (%TS)	1.39 %
% TS feed	95.00 %

	N	P
Feed (input)	2187	400
Produksjon	1830	184
Biomass Fisk : Planter	1	4.3

Akkumulert NO ₃ -N (g):	701
Akkumulert PO ₄ -P (g):	22

*C) Modelled fish production for Norwegian aquaponic pilot unit
(SGR=2%, FCR=1) (fish harvest twice per month)*

FIGURE 2. Modelled fish production for Norwegian aquaponic pilot unit (SGR=2%, FCR=1) (fish harvest 2 x per month)



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Abstract: The main objective of AQUAPONICS NOMA (Nordic Marine) was to establish innovation networks on co-production of plants and fish (aquaponics), and thereby improve Nordic competitiveness in the marine & food sector. To achieve this, aquaponics production units were established in Iceland, Norway and Denmark, adapted to the local needs and regulations. Experiments were performed to investigate suitable fish and crop species for Nordic aquaponics in terms of growth, quality, effluents, temperature and nutrient balances. Further efforts have been made to optimize management practices and technologies in aquaponics, e.g. treatment of wastewater and solid wastes to protect the environment from pollution and pathogens. The project has designed commercial scale aquaponics production models for the Nordic region, and investigated consumer market potentials including the possibility for Eco-labeling. The study has demonstrated that aquaponics may be a viable component in Nordic food production, both at small scale (urban aquaponics) and in large scale combinations of agri- and aquaculture. The results have been and will be disseminated to the public and to the scientific community.		
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Aquaponics NOMA

New Innovations for Sustainable Aquaculture in the Nordic Countries

Our future well-being depends on sustainable use of our natural resources, and the Nordic Countries aims to be at the forefront of the Green Shift.

With this project, Denmark, Iceland and Norway have collaborated to find new production models for reuse of nutrients from aquaculture industry to plant production in a 100 % closed loop, or will it be better to reuse 80-90% of all water in recirculated aquaculture systems, connected with a plant loop? Read about our findings, and you will be surprized.

Aquaponics do work and participants in the project produced rainbow trout, brown trout, arctic char, red tilapia, silver tilapia and pikeperch.

Nordic Innovation is an institution under Nordic Council of Ministers that facilitates sustainable growth in the Nordic region. Our mission is to orchestrate increased value creation through international cooperation.

We stimulate innovation, remove barriers and build relations through Nordic cooperation