SPECIAL REQUIREMENTS OF AQUAPONICS IN FINLAND

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Bachelor's thesis
April 2016
Degree Programme
in Environmental
Engineering

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ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Environmental Engineering

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Bachelor's thesis, 66 pages, appendices 7 pages
April 2016

This thesis brings together observations about special features that should be taken into consideration when designing the technical aspects of aquaponics practices and production units in Finland. Market demands, water purification and facility temperature control methods; sources of healthy feed and the needs for artificial lighting vary significantly around the globe. The unique combination of climate conditions, legislation and zoological conditions should be taken into consideration when approaching the implementation of aquaponics production facilities.

This study is conducted by comparing the special features in the Recirculating Aquaculture Systems and Greenhouse production systems in Finland. The aim of this study is to compile relevant research results that can further assist in identifying, how aquaponics can be made to be a profitable business in Finland.

The analysis of material supports the conclusion that aquaponics production in Finland may be a sustainable and profitable food production method. Important design factors are the response to market demands, efficiently utilized sources of energy, unobstructed workflow and automation within the production facilities.

Finland has clean air, water and soil and its climate makes it have a low level of fish and plant diseases and parasites. These benefits could be advantageous in the multi-trophic aquaponics production along with other greenhouse and aquaculture production methods.

Key words: aquaponics, recirculating, aquaculture, greenhouse, production, nordic, finland

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CONTENT

ABBREVIATIONS AND TERMS

Aquaculture	Fish Farming
Aquaponics	Integrated Hydroponics and Aquaculture
BOD	Biological Oxygen Demand
CHP	Combined Heat and Power
DO	Dissolved Oxygen
DWC	Deep Water Culture
HID	High Intensity Discharge
Hydroponics	A group of soilless farming methods
LED	Light Emitting Diode
NFT	Nutrient Film Technique
RAS	Recirculating Aquaculture System
PAR	Photosynthetically Active Radiation

1 INTRODUCTION

This thesis was inspired by a wide range of aquaponics research and studies around the world. In the beginning of 2015 it was noted that this production method has not yet been publicly researched in Finland. Most of the available research was conducted in warmer climates and different sun patterns. To find out can the aquaponics systems be profitably operated in Finland any special requirements Finnish conditions impose on the aquaponics industry needs to be identified and the available solutions compared. This thesis focuses on listing the Finnish climatic, legal and zoonotic conditions related to aquaponics operations. Aspects of potential renewable energy solutions are also discussed.

The idea of constructing a small prototype system was a starting point towards understanding how the aquaponics systems operate in practice and how the different variables in water and air quality effect the system functionality. The project team Benjamin MacNab, Daniel Bodenmiller and Olli Soppela established a project named E-Fishient, designed a prototype and applied for project sponsoring from various companies in Finland and Germany. Elobau Ltd from Germany sponsored the materials for the project, TAMK sponsored the test area and Maa ja Vesitekniikan Tuki (MVTT) gave a small grant for electric components. These resources accompanied with the work conducted by the project team established an aquaponics pilot system to be researched.

Many design, manufacturing and maintenance mistakes were done along the way from misbalanced flow rates to leaking pipe connections, unbalanced feeding rates, oversized fish introduction, plant micronutrient deficiencies, unstable water temperatures insufficient lighting and pH imbalances. After several months of trials and adjustments a controllable and chemically balanced circulation system without leakage risks or chemical alterations was established.

The experiences from the faced challenges led to an understanding about the special requirements aquaponics producers need to take into consideration in Finland. The thesis aims to introduce the basics of aquaponics and how the different components can be adjusted for Finnish conditions.

The thesis describes energy and water related natural conditions in Finland, introduces basics of aquaponics technology and discusses some renewable energy solutions in Finnish aquaponics.

FIGURE 1. E-Fishient aquaponics pilot design (Macnab & Bodenmiller).

PICTURE 1. E-Fishient aquaponics pilot system (Olli Soppela 2015).

2 NATURAL CONDITIONS IN FINLAND

Finland is one of the most populated northern areas in the world. Due to the effects of the Gulf Stream Finland stays habitable during the winter time. The northern location nevertheless generates cold peaks in the winter and provides extraordinary lighting conditions throughout the year. Long winter and short summer nights cause high variance in the needs of artificial inputs in aquaponics production.

2.1 Finnish Climate

According to the European Commission Joint Central Research Centre most of Finland belongs to the "cool temperate, moist" climate zone. Also Sweden, Norway, Denmark, Iceland and southern parts of Canada belong to the same climate zone (IPCC 2006). This definition helps to identify similar conditions where these research results can be applied in.

2.2 Thermic Period in Finland

Since aquaponics is both aquaculture and greenhouse production the seasonal thermal conditions affect a lot how much aquaponics requires heating and lighting. Observing this the thermic period gives a good overview about the timeframe of greenhouse production in Finland.

The thermic growth period is defined to be the period during the year that the average monthly temperature exceeds 5 °C. In Turku this period is from the mid-April to late October. Temperature changes in Turku (60° latitude) vary on average 22 °C between summer and winter. Temperature changes in Sodankylä (67° latitude) on average 28 °C between summer and winter. These naturally high temperature variations put pressure in the temperature control systems' energy demands in the greenhouses and inland aquaculture systems in Finland. (Ilmatieteenlaitos 2015)

A climate where the variation of weather conditions may vary from more -30 °C to +25 °C impose heavy requirements on temperature control systems in the Finnish greenhouses - especially for facilities that aim for year around operation (Särkkä et al 2008). Temperature average changes in Finland may vary up to 30 centigrade between summer and winter (Ilmatieteenlaitos 2015).

Throughout Finland the average winter temperature in the winter of 2014-2015 was from 1.5 to 4.0 centigrade higher than the average of the past 30 years (Kurppa et al 2015:12). This might indicate that the average winter temperatures in Finland are warming, which should be taken into account when simulating and designing the thermal control systems for aquaponics facilities.

The attached heat sum map illustrates the total of daily solar irradiation averages throughout the country. This map compares the natural light conditions in different parts of Finland.

2.3 Natural Light Conditions

Also the nordic latitude (55 to 65 degrees) provides unique lighting conditions that require both shading during the summer (Särkkä et al 2008) and supplemental lighting during the winter (Anderson 2010) to stabilize the optimal plant production levels. Also layers of snow on horizontal surfaces pose light blockage and physical stress to the structures. These issues require consideration during the design, construction and maintenance of the aquaponics greenhouse operations.

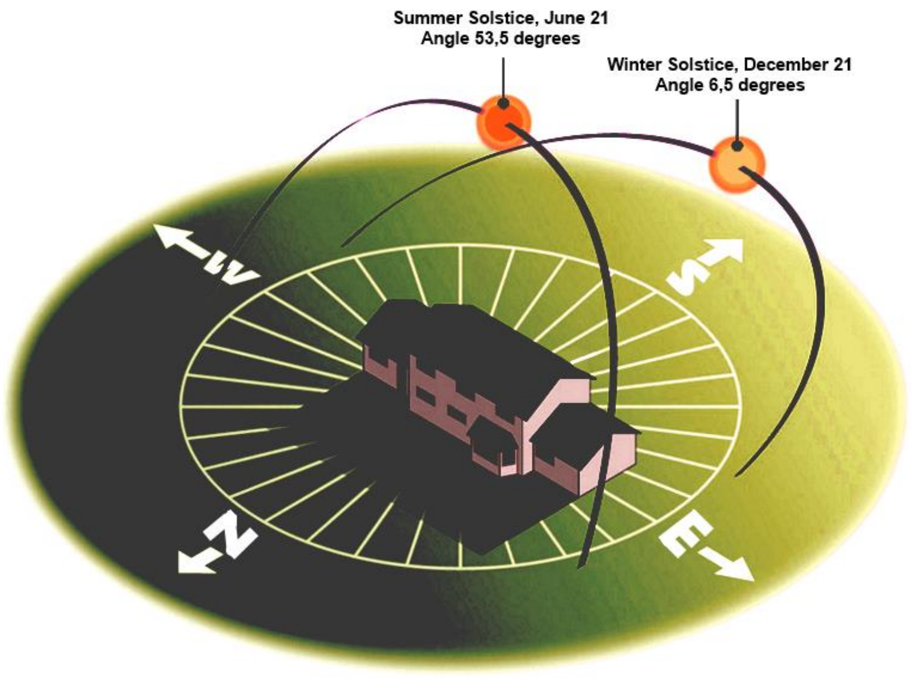

FIGURE 2: Angles of Solstices in the 65° latitude (Soppela 2015)

The sun solstice angles are important variables when planning for the utilization of solar irradiation in terms of passive solar heating, solar thermal heaters, photovoltaic solar panels and optimal grow light intensity. During the winter solstice the sun shines at 6.5 degrees and during the summer solstice at 53.5 degrees (UO Solar Radiation Monitoring Laboratory, 2007).

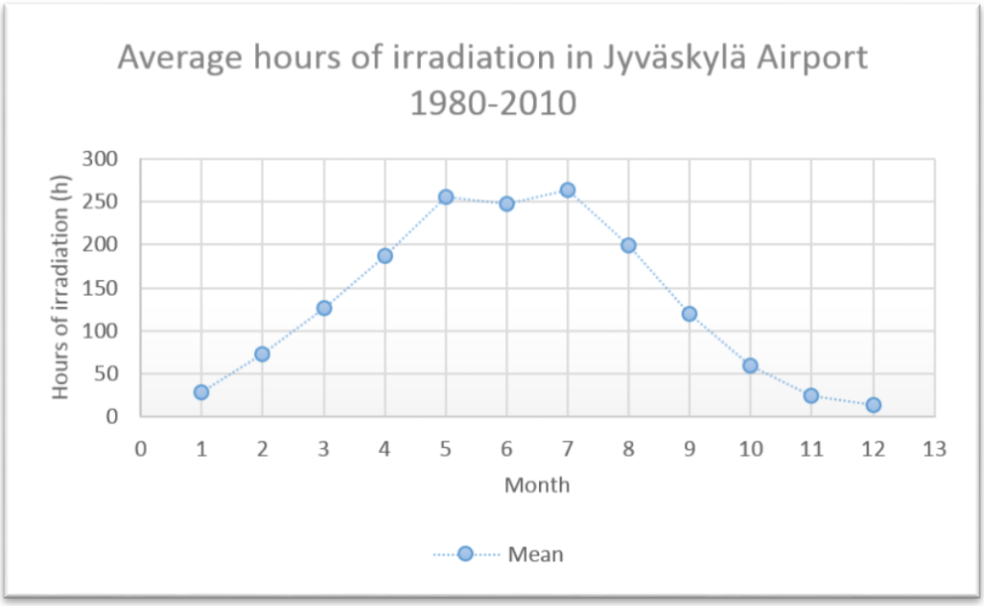

FIGURE 3. Average monthly solar irradiation in Vantaa 1981-2010
(Data from Ilmatieteenlaitos 2015)

The seasonal illumination differences are illustrated in the Figure 5, representing the collected data between 1980-2010 from Jyväskylä airport. Data shows that the average sunlight hours vary from total 14 hours in December to total 263 hours in July. Amount of light varies significantly depending on the declination of Earth related to the Sun and the amount of clouds in the atmosphere blocking the irradiation. The large variation in the average monthly irradiation poses pressure towards utilizing artificial lights during the winter months to provide sufficient light intensity for efficient photosynthesis in the greenhouses (Lehtonen 2002).

3 INTRODUCTION TO AQUAPONICS

Aquaponics is a food production method that combines hydroponic and aquaculture farming techniques. These two nutrition production techniques operating synergistically create a system that functions symbiotically with little to no need for synthetic inputs such as chemical fertilizers, toxic pesticides or herbicides (Ash 2014).

The system is based on an artificial closed circulating ecosystem including aquatic animals such as fish in water tanks and terrestrial plants in hydroponic grow beds. The technique allows simultaneous cultivation of various nutritious food products suitable for human consumption.

Different aquatic animal species of different age require different amounts of purified and oxygenated water; pellet feed of suitable consistency and size; sufficient water treatment processes; diverse and activating water environment; and the right intensity and spectrum of light.

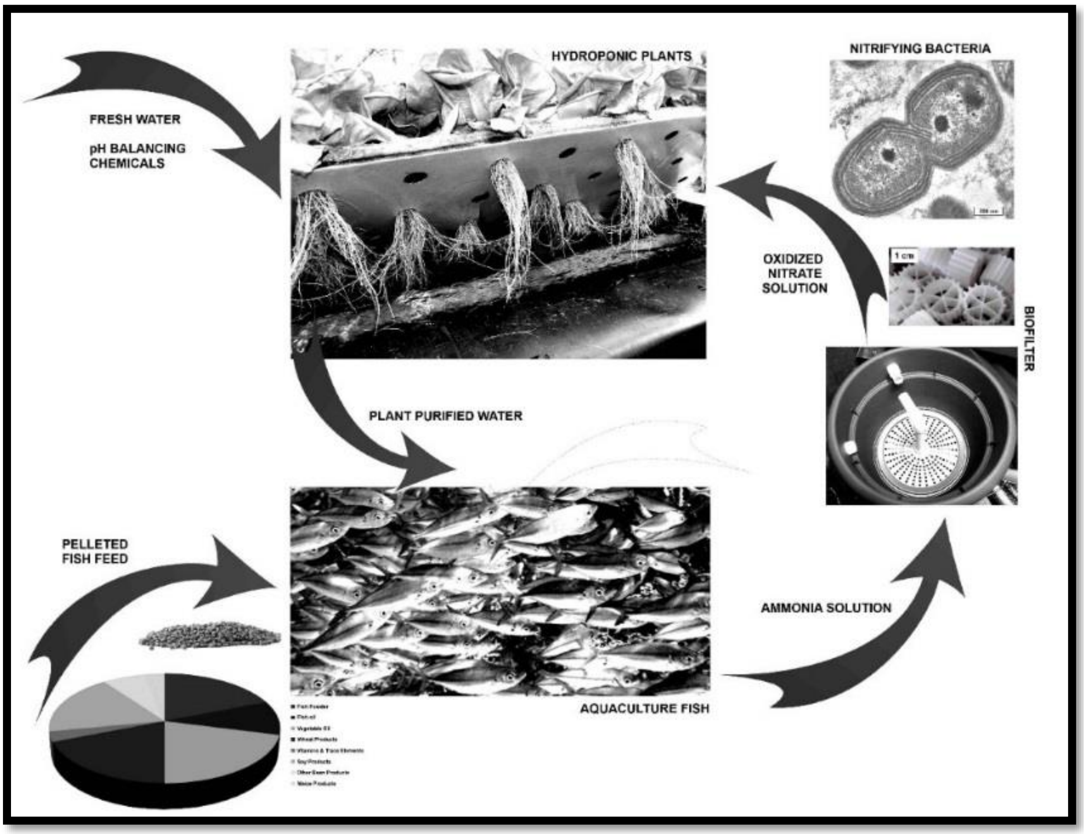

FIGURE 4. Operational principles of aquaponics process (Soppela 2015)

Fish feed provides the nutrients into the system. First fish absorb nutrients from the feed to grow tissue and defecate the unabsorbed nutrients as feces. The nitrifying bacteria *Nitrosomona* and *Nitrospira* oxidize the ammonia in the fish excrete converting it first into nitrites and ultimately into nitrates. Nitrates can be utilized by the terrestrial plants in their growth. Partially purified water returns from the hydroponic systems back to the aquatic animal pool or tank.

This relatively sensitive synergy has to be well maintained and balanced to provide optimal growing conditions for each type of organism within the system. Different species often have slightly different requirements for temperature, oxygen, pH and nutrient levels in the water. Therefore, it is extremely important to be able to control these parameters in order to keep them within the tolerance levels of each organism within the system (Nelson & Pade 2008).

To keep the balance in the close-loop system, multiple control mechanisms have to be utilized due to the high variance in annual the temperature and light conditions in the Finnish climate.

3.1 Process Diagram of an Aquaponics Facility

Broad overview about the process diagram of aquaponics can be found in the Figure 7 below. It describes the different water control phases within the system. Input water is first disinfected from any potential disease carrying pathogens in an UV or ozone treatment process (Sonntag et al 2012). Disinfected input water is then cooled or heated depending on the season and the requirements of the aquatic animals grown in the system. Cleaned and thermally balanced input water is diluted with the existing circulation water where it goes into the mechanical treatment phase. In the mechanical treatment drum and swirl filters remove excess solids from the water circulation. Sludge from the aquatic animal feces gets trapped in this stage and it can be utilized later in the biogas production or plant cultivation (Gigliona 2014) and potentially in hydroponic fertilizer production.

After the mechanical treatment water is channeled into biological treatment, where the aerated high surface area accommodates nitrifying bacteria species, which convert the ammonia from aquatic animal discrete into oxidized nitrites and nitrates. The oxygen levels of the water are further increased after biological treatment by aerating the water. Dissolved oxygen level of the water mass is constantly monitored and controlled to keep it in the optimal level for each phase.

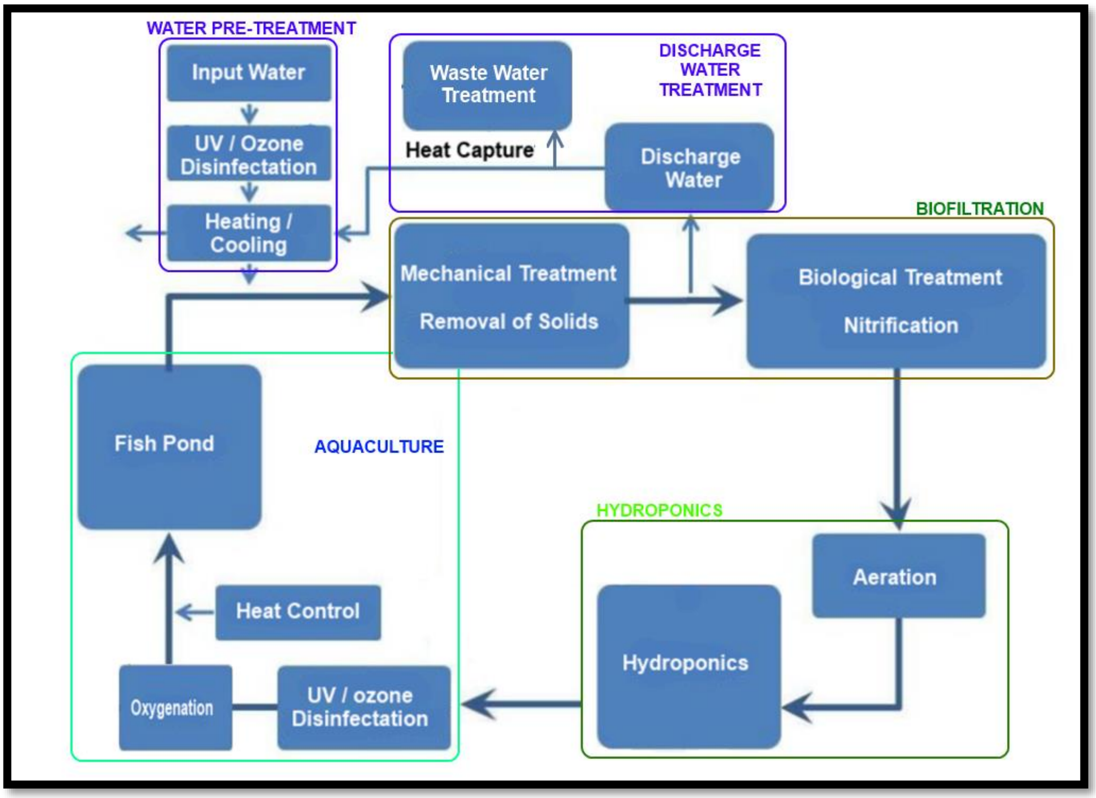

FIGURE 5. Basic process diagram of an aquaponics process (Soppela 2015)

Circulating water carries the biologically treated fish feces as fertilizers to the plants. The water is further filtered through the growth media of the hydroponic systems where terrestrial plants absorb part of the nitrates and phosphates produced in the biological treatment phase.

Some slowly soluble micronutrients can be manually added to the growth substrate of the plants to further increase the nutrients available for the plants. It is important not to add too many nutrients for the aquaponics to prevent the aquatic animals from getting stressed about the chemical changes in the circulation water (Rakocy 1993).

After the hydroponic process water is further disinfected, oxygenated and heat controlled to obtain the optimal conditions for the growth of the aquatic animals.

The mechanical, biological and hydroponic water purification processes are very important for the health of the aquatic animals. Too high levels of ammonia in the fish tanks may lead to extensive damage to tissues, especially the kidney and the gills, impaired growth, decrease in the immunity system and death of the fish (Blidariu et al 2011).

Excess CO_2 is removed by trickling the water through a ventilated vertical structure. The removed CO_2 from the water can be channeled into the greenhouse to increase the plant growth (Timmons et al 2007).

From the aquatic animal reservoirs water goes back to the mechanical treatment phase and gets diluted with the input water stream. Water gets removed from the system through sludge discharge, evaporation, washing, controlled runoff and within the tissues of aquatic animals and terrestrial plants (El-Saye 2006).

4 AQUAPONICS COMPONENTS

Aquaponics systems consist of three main components; aquaculture, bio-filtration and hydroponics. These components are introduced in this section.

4.1 Aquaculture

Aquaculture means the process of aquatic animal farming. This can be done in the oceans by restricting the movement of aquatic animals with nets or cages and feeding the animals to enhance the growth rates. Aquaculture can also be done in inland ponds or facilities where the environment is more controlled providing good conditions for process optimization, legal requirements for waste management are tighter and the overall operational costs are higher.

In Finland the average size of aquaculture project production is 60 tons per year, in Sweden 400 tons per year and in Norway 1000 tons per year. All countries have majority of the production in open sea areas. Average fish maturity cycle is from 2 to 3 years. In 2013 there were 310 companies operating 471 aquaculture facilities in Finland having combined turnover of 57.9 million euros. It is estimated that with the support and logistics services added, total turnover of fish related operations in Finland is 175 million euros annually. Average turnover of all Finnish aquaculture companies was 389 000 euros (Laitinen 2014).

In Finland most profitable form of aquaculture was the food fish production in the ocean, inland fish production in average was not profitable in 2011. Total production of edible fish in Finland in 2013 was estimated to be 13.6 million kg; from which 89.7% was salmon and 8.8% whitefish. 84.5% of the production happened in the ocean and 15.5% in inland facilities. Finnish exchange balance in fish production and consumption is 300 million euros on minus. This indicates that the high demand of fish products is mainly filled with imports - only 20% of demand supplied locally. This is partly due to the low import prices of salmon from the big open sea farms in Norway, which with its externalized waste management costs is a cheaper production method than inland operations. In comparison 90% of Finnish cattle meat consumption is produced locally.

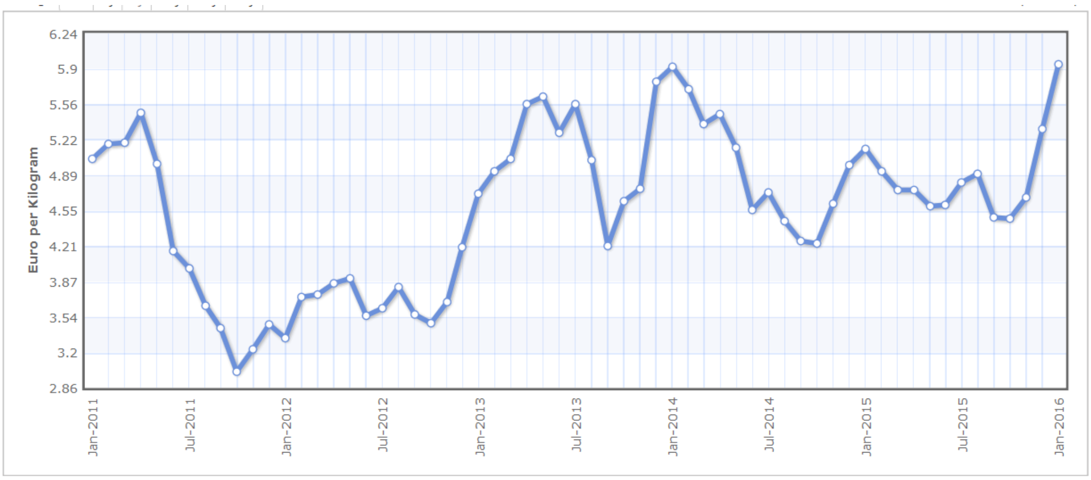

FIGURE 6. Global salmon price index 2011-2016 (Data: Index Mundi 2016)

Aquaculture in Finland faces a lot of bureaucracy as the only primary production sector requiring environmental permits. Total amount of approved aquaculture permits has decreased annually for 7 years in a row which makes scaling up the self-sufficiency in fish production challenging (Laitinen 2014;20).

According to the statistics 70% of Finnish fish is exported representing €41M value exported out of €58M of total production. The value is relative to the 2014 consumer price index (LUKE 2015). Simultaneously the value of imported fish has doubled in 10 years (LUKE 2015). Both figures indicate that Finnish companies are actively trading fish products beyond Finnish borders.

In 2013 New Scientist headlined that majority of global fish consumption will come from aquaculture projects by 2015 and total fish consumption will exceed total beef consumption (Marshall 2013). This indicates global increase in aquaculture production.

4.2 Bio-filter

Bio-filtration processes are commonly used in waste water treatment to remove nitrogen and carbon based elements from the water. In conjunction with mechanical and chemical treatment most municipal water treatment systems utilize biological treatment in their purification process. The same bacteria operate in waste water treatment systems and in aquaponics bio-filters.

The role of the bio-filter is to accommodate large colonies of nitrifying bacteria such as *Nitrospira* and *Nitrosomonas*. Growth rates are improved creating preferable conditions to the grown bacteria. Warm water with plenty of oxygen, plenty of surface area, neutral or slightly acidic pH and no light are the circumstances where nitrifying bacteria thrive. Nitrifying bacteria are photophobic and light, especially UV light inhibits their growth (Alleman et al 1987). *Nitrospira* also has its important ammonia-oxidizing enzyme deactivated in the presence of blue light (Hooper et al 1974). The effects of light exposure are not as significant for an established culture, but photons may reduce and inhibit the expansion of cultures to new surfaces.

The size of the bio-filter has to be aligned with the stocking density of the aquaculture pools, otherwise the nitrifying process might start producing hydrogen sulfates which are dangerous to the aquatic animals (Nootong et al 2011).

TABLE 1. Temperature Effect on nitrification rate of nitrifying bacteria (Gerardi 2006)

Temperature (C°)	**Effect of Nitrification**
30	Optimum temperature for nitrification
15	Approximately 50% of optimum nitrification
10	Approximately 20% of optimum nitrification
5	Nitrification ceases

TABLE 2. DO Effect on nitrification rate of nitrifying bacteria (Gerardi 2006)

Dissolved Oxygen (mg/L)	Effect on Nitrification
< 0.5 *	Nitrification initiated but insignificant
0.5 - 0.9	Rate of nitrification begins to accelerate
1.0 - 2.0	Rate of nitrification significant
2.1 - 2.9	Sustained nitrification
3.0	Maximum rate of nitrification
> 3.0	Nitrification may improve

TABLE 3. The pH effect on nitrification rate of nitrifying bacteria (Gerardi 2006)

pH	Effect on Nitrification
4.0 – 4.9	Nitrifying bacteria inactive but present
5.0 – 6.7	Nitrifying bacteria stunted activity
6.8 - 7.2	Optimal pH range for activated sludge nitrification
7.3 – 8.0	Assumedly constant range of nitrification
8.1 – 8.5	Theoretical optimum pH range for nitrification

These key parameters in the flow-through water define the effectiveness of the nitrification process within the bio filter. Tables provide useful ranges for both RAS and aquaponics bio filtration.

4.3 Hydroponics

There are three most commonly used soilless hydroponic methods utilized in plant production. These methods are Substrate Growbed Method, Deep Water Culture and Nutrient Film Technique.

TABLE 4. Comparison of Hydroponic Technologies (based on Goddek et al 2015).

	Substrate Growbed	***Deep Water Cultivation***	***Nutrient Film Technique***
Advantages	*- Bio-filtration - Solid Filtration - Mineralization - Area for Microflora - Stabile Water - High Nutrient Uptake - Assists plants to stand with roots*	*- Constant Flow - Small Sump - Easy maintenance - Stabile Water - High Nutrient Uptake - Thermal battery*	*- Constant Flow - Small Sump - Light Weight - Easy to stack - Flexible shape*
Disadvantages	*- Large Sump - Difficult to Optimize - Heavy Infrastructure - Hard Maintenance - Clogging Risks*	*- Separate Bio-filter - Heavy Infrastructure - Aeration Required - Does not help plants to stand*	*- Unstable Water quality - Low Nutrient Uptake - Lower yields - Expensive materials*
Summary	*Good method for perennials and other bigger plants*	*Good method for small quick cycle plants*	*Good method for limited spaces and decorative setups*

4.3.1 Substrate Growbed

This method utilizes a water insulated container filled with a growth substrate, such as expanded clay, perlite, pumice, gravel, coconut fiber or peat. The substrate bed is flooded with the water in regular intervals and emptied automatically using the "Ebb and Flow" technique that operates using a bell syphon. This method is good for big plants that require substrate in the root zone to keep the fruit bearing stems in balance. Method also works well for perennials that do not require constant harvesting and replanting.

Heavy maintenance, heavy weight and need for sump tanks does not make growbeds ideal for short cycle plants or roofs with limiting carrying capacity. Well scaled modularity in the size of the plant pots can increase the workflow efficiency significantly.

PICTURE 2. Substrate Growbed (Daniel Bodenmiller 2015)

4.3.2 Deep Water Cultivation (DWC)

Deep Water Cultivation method utilizes a large body of water, where the plants grow by floating on a raft on top of the water mass. The roots grow straight into the water from the raft and no substrate is required. DWC requires little work in the planting and harvesting phases. This method fits well for small lettuce and herb plants that have a quick growth cycle, since small plants do not require support against gravity from their roots.

In case of raft hydroponics, the grow bed area should be 1 m_2 per 180g fish feed per day to supply a sufficient nitrification treatment capacity (Rakocy, et al., 2006, p. 7).

PICTURE 3. DWC Raft Principle (CC 3.0 Bryghtknyght)

4.3.3 Nutrient Film Technique

Nutrient Film Technique uses gutter-like channels or pipes to circulate water to the plant roots. A thin nutrient solution film is circulated in the pipes to have a large area irrigated. This method is light and fits well for vertical farming and roofs, where the weight stress for the holding structure should be low. The weight can be concentrated into one column where the main water reservoir stands. Grown plants have size limitations and their roots should not be able to block the drain pipes.

NFT systems are vulnerable to temperature changes. The nutrient solution in the NFT pipes may very well overheat in long circulation systems that get exposed to direct sun-light. This challenge may be addressed by shortening the NFT water circulation cycles or by having a separate cooling ventilation system within the NFT piping.

PICTURE 4. Nutrient Film Technique (Daniel Bodenmiller 2015)

PICTURE 5. Nutrient Film Technique (Ildar Sagdejev, 2009, CC-BY-SA 3.0)

5 AQUAPONICS WATER QUALITY

The various organisms in aquaponics have usually different optimal growing conditions. Table 1 below lists the optimal water conditions for each organism and concludes a good average to be used in an aquaponics system.

TABLE 5. Water quality parameters for different growth systems (Somerville et al 2014).

Type	Temp	pH	Ammonia (mg / l)	Nitrite (mg / l)	Nitrate (mg / l)	DO (mg / l)
Warm water fish	22-32	6-8.5	< 3	< 1	< 400	4-6
Cold water fish	10-18	6-8.5	< 1	< 0.1	< 400	6-8
Plants	16-30	5.5-7.5	< 30	< 1	-	> 3
Bacteria	14-34	6-8.5	< 3	< 1	-	4-8
Aquaponics	18-30	6-7	< 1	< 1	5 - 150	> 5

Since hydroponic production happens in artificial conditions, where soil has not been built over the years, a special kind of nutrient solution has to be prepared to provide the sufficient amount of various nutrients for the plants (Resh 2004).

Preferred nutrient solution for hydroponic farming is an aqueous solution that contains inorganic ions from soluble minerals. Seventeen elements have been identified to be vital for plant growth. These essential substances are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, copper, zinc, manganese, molybdenum, boron, chlorine and nickel (Asao 2012).

Plants obtain the carbon and oxygen from the atmosphere and the rest is to be supplied by either the growth medium or nutrient solution. Also other elements such as silicon, sodium, selenium, vanadium, cobalt, aluminum and iodine are considered beneficial for plant growth in very small quantities because they can either stimulate the growth or compensate the toxicity of other substances, or can replace some essential nutrients in a less specific role (Trejo-Téllez et al. 2007).

All the necessary primary, secondary and micro-nutrients are required in the plant growth solution and these have to be made available either through a careful formulation of the fish feed or as added chemicals in the hydroponic circulation (Mallick 2005).

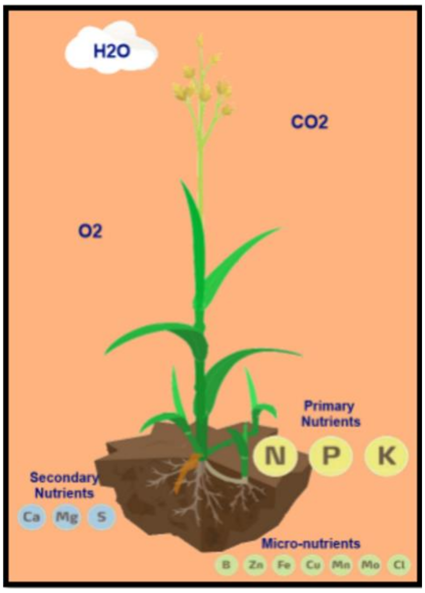

FIGURE 7. Plant Nutrient Requirements (Soppela 2015)

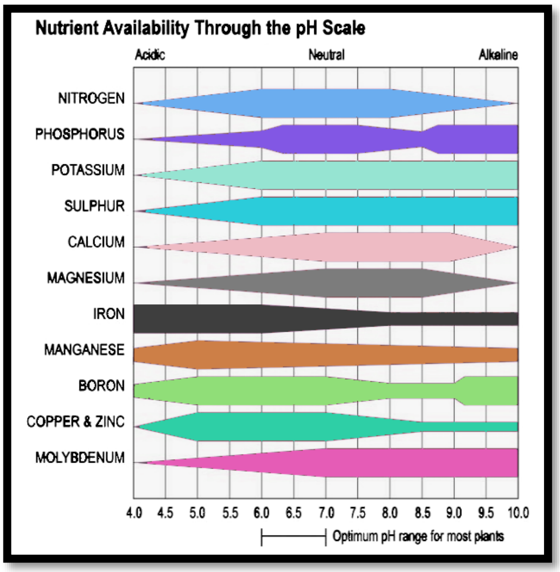

FIGURE 8. Effect pf pH on the uptake of nutrients by plants (Data from Ivanic 1984)

In hydroponic and aquaponics systems the plant biomass growth rates are tightly related to the nutrient uptake rates which are dependent on the pH conditions of the solution (Marschner 1995). The changing pH alters the ionic structure of the elements and mole-cules in the solution, from which only the certain type of structures can be absorbed by the plant roots. Figure 10 above shows average absorption rates of elements in different pH conditions.

6 ARTIFICIAL LIGHTING IN AQUAPONICS

Light is electromagnetic radiation that consists of quantum called photons, which energy levels depend on the wavelength of light (Jenkins 2008). Cost-efficient growth operations in Finnish conditions require extended lighting period between early October and late April (Särkkä et al 2008).

Due to the low availability of solar irradiation during the winter season, artificial lighting has to be well designed, chosen and installed into aquaponics facilities in Finland to maintain stable year around production. Aquaponics systems cannot operate sufficiently without the hydroponic systems that require applied photon stream of right spectrum to upkeep Chlorophyll a and b photosynthesis.

In high latitudes, raising light intensity and applying inter-row lighting may lead to higher yields in autumn to mid-winter without affecting the efficiency of electricity use. In spring and summer seasons utilizing artificial lighting decreases the efficiency. Using supplemental photosynthetically active radiation is significantly lower in terms of efficiency during the summer than in other seasons. (Kaukoranta et al 2014).

Light improves the plant growth, heats the facilities and can be used in integrated pest management (Shimoda et al 2013).

6.1 Electromagnetic spectrum required for photosynthesis

Different lighting systems provide different output ratios of electromagnetic spectrum. Plants can utilize in growth only some of the spectrum referred to as PAR (λ = 400 to 700 nm). Especially the operational range of Chlorophyll a and Chlorophyll b is important in the process of plant growth, and the light spectrum should operate in the spectrum levels favorable for the energy utilization of Chlorophyll pigments [Lambers et al. 1998:29]. Chlorophyll a has the peak photon absorbance levels in 420nm and 680 nm wavelengths. Chlorophyll b has the peak photon absorbance levels in 490 nm and 630 nm wavelengths (Larkum 2003).

Different spectrums and intensities of light make the plants to grow in different patterns and shapes. High levels of blue light (6500 K) enhance growth of long internodes, cause formation of less branches and enhance length increase in the plant structure. This spectrum is more used in the vegetation phase. Plants grown under high levels of red light (2700 K) have less internode elongation and grow shorter. This spectrum is more used in the blooming phase. Plants that gain lower exposure to photons tend to grow longer, aiming to reach more light intensive levels of the surrounding canopy (Arteca 2015 p. 341).

6.2 Efficiency comparison of natural and artificial light

Direct sunlight provides around 2000 micromoles $m_2 s_{-1}$ of photons. Transparent surfaces reflect and absorb on average 30% of the photons, so around 1400 micromoles $m_2 s_{-1}$ photons from the Sun reach the plant leaves in greenhouses. Sunlight provides power in total around 1000 W / m_2. So far the best LED systems can provide 1.74 micromoles of photons / J, leading to the total provision of 1400 micromoles per $m_2 s_{-1}$ with approximately 800W / m_2 power (Bugbee 2015). This calculation does not take into account the optimal light spectrums, which are well adjusted in LED-lamps and much more broad in direct sunlight.

Different lighting sources provide different kind of spectrums. Currently the most widely used lighting technology in Nordic countries is the high-pressure sodium discharge lamps. This technology operates in the power range between 100 and 1000 W providing a diverse spectrum according to the following ratios:

TABLE 6. 400W HID Lamp photon emission (Anderson 2010)

Wave length area	**425 – 475 nm (blue)**	**625 – 675 nm (red)**	**400 – 700 nm (PAR)**	**700 – 830 nm (infrared)**
Power	4.97 W	21.44 W	141.38 W	42.22 W
Photon flux	18.96 µmol/s	116.25 µmol/s	705.74 µmol/s	282.41 µmol/s

This indicates that 35% (PAR 141W / Total 400W) of the current HID lamp radiation emissions hit the peak spectrum range that can be utilized by the plant photosynthesis conducting pigments (Anderson 2010). The rest of the released spectrum (infrared) can be utilized in the greenhouse heating, since the seasons when supplemental artificial lighting is required has colder outside temperatures, which usually leads to a need for more heat generation in the facility.

6.3 Lighting Interval for plant activation

Commonly vegetation period of plants requires more light hours per day than the blooming period. This is due to the evolution of plants in conditions, where the warm summer time is usually the season for seed germination and growth. Cooler and shorter days give indications to the plant that the growth period starts to end and blooming to make seeds has to begin. Light conditions in the vegetation phase can be from 16 to 24 hours of light, while the blooming phase of most plants strengthens when the lighting duration is dropped between 8 and 20 hours per day. To conserve energy, lamps can be set to be on only 6-10 minutes every half an hour for the periods that extends daily 12 hours of illumination. This should stimulate sufficiently the plants and increase the growth rates while consuming less energy (Runkle 2011).

7 ENERGY SYSTEMS IN AQUAPONICS

Energy efficiency is one of the biggest single contributors to profitability of inland aquaculture and year around greenhouse operations in Nordic conditions (Keitaanpää 2011). The energy needs for aquaponics in the northern conditions are focused on artificial lighting and temperature control of the greenhouses and fish tanks. The focus of greenhouse energy consumption has shifted from heavy oil to electricity during the past 10 years as shown in Figure 11 below.

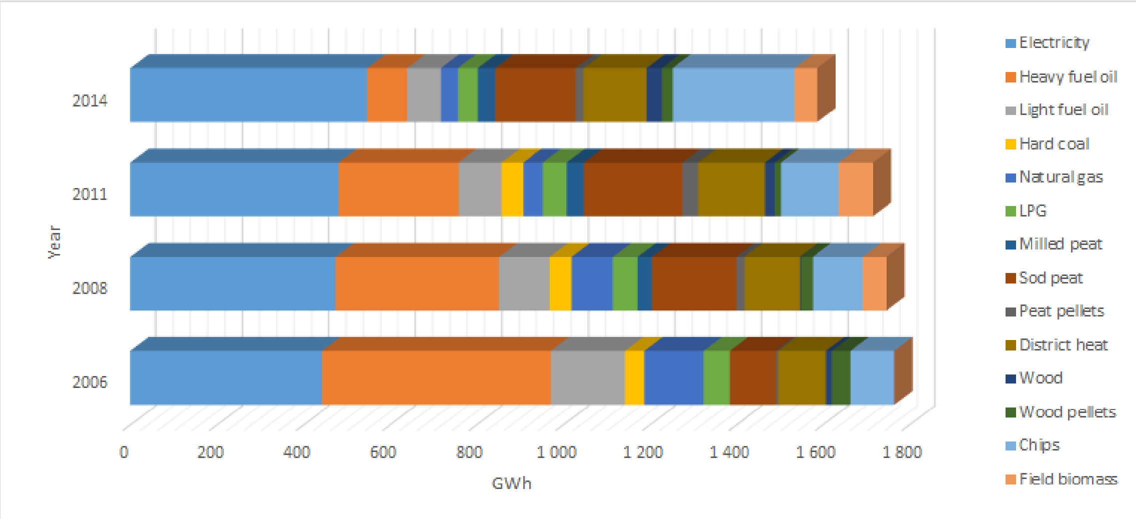

FIGURE 9. Total energy consumption of Finnish Greenhouses between 2006 and 2014 (Data from LUKE 2015)

Establishing the RAS, greenhouse production and aquaponics facilities next to heavy industry can halve the cost of electricity by utilizing the existing electricity infrastructure (Tuomainen et al 2011).

For year around production supplemental artificial lights are required most of the year. Rapid reduction in market prices of plant growth optimized-spectrum LED lights can dramatically reduce the electricity demand of artificial lighting (Anderson 2010).

Efficient temperature control is another significant consumer of energy. Heating can be done with excess process heat, district heat, electrical heat, combustion heat, compost heat, ground heat or solar heat. Heating requirements may be lowered with sufficient insulation, thermal batteries and recirculating heat pumps. Multiple pumps, motors and sensor control systems have also their impact on the electricity demands within an aquaponics greenhouse operation. These solutions are described in the next section "*Thermal Control Systems"*.

Flow-through ventilation cooling removes heat, moisture and carbon dioxide from the greenhouse. This common method might alter the optimal microclimate conditions for plant growth since availability of CO_2 is many times a limiting factor for plant growth. A droplet-screen cooling technology has shown significant potential in thermal control without altering the greenhouse gas balance. This technology will still consume significant amount of energy since significant volumes of water need to be pumped to the ceiling level of the greenhouse (Särkkä et al 2008).

7.1 Thermal Control Systems

Temperature control is important for the optimal growth rates of the grown species. For example, a plant species *ageratum* will go twice as fast in similar conditions if the temperature is raised from 14 °C to 23 °C (Runkle 2011). Salmon species *Oncorhyncus gorbuscha* has been studied to grow 100% faster in identical conditions when water temperature is raised from 4 °C to 12 °C (Savikko et al 1993).

Both heating and cooling systems play significant roles in the energy consumption of greenhouses in the Nordic conditions. The more closed the greenhouse is, the more its climate conditions can be controlled to provide optimal growth conditions for the grown species. Half-closed greenhouses assist in keeping CO_2 levels high most of the season while reducing the investment costs for the cooling devices for the peak temperatures and having the capability of low-cost blow-through ventilation. Open greenhouses tend to suffer from CO_2 losses which lead to reduced harvests (Särkkä et al. 2008).

The sufficient thermal control capacity is depending on the species preferences within the aquaponics operation, volume of water, volume of air, ventilation systems, alternative sources of heat energy and insulation capacity of the outer structures.

7.1.1 Internal Process Heat Utilization

Excess light source heat can be utilized in the greenhouse thermal control processes. HID lamps generate heat out of 65% of the electricity they consume (Anderson 2010). For commercial scale operations, the electricity consumption of all of the installed HID lamps is counted in tens of kilowatts at their lowest levels. The artificial lighting is kept on from 4 to 24 hour a day depending on the grown species and season creating a significant flow of energy into the greenhouse. 35% of this energy is converted into photons with the wave length that can be absorbed by the photosynthesizing pigments (Anderson 2010). Only a fraction of this right spectrum radiation is absorbed by the organisms and the rest is converted into heat.

7.1.2 External Process Heat Utilization

Excess heat from other industries such as power generation or other heavy process industries can be channeled into aquaculture systems to increase the energy efficiency of industrial ecosystems. Establishing aquaponics operations next to existing industrial electricity infrastructure saves initial costs and can halve the electricity costs of the facility due to already existing infrastructure. Nearby heavy industry may also have excess process heat that can be utilized in thermal control of the facilities (Tuomainen et al 2011). Modern industrial areas usually have good logistics connections, situation mapping and required support services to establish industrial scale operations.

7.1.3 Thermal Controlling of the Greenhouse Microclimate

Warm air rises to the top of the greenhouse while cool air lowers down near the floor. Temperature can be balanced by positioning fans – and ventilation piping in bigger structures - in the opposite corners of the greenhouse to create an oval shape air circulation within the greenhouse. This method can be used to either heat or cool the plant microclimate or process water within the greenhouse. Shading curtains can be utilized to cool down greenhouse air. Shading curtains can also lower intolerable solar irradiation levels.

A droplet cooling method sprinkles cold water fog to the greenhouse absorbing thermal energy from the greenhouse climate. This cooling method can increase the annual production of cucumber and tomato up to 15-25% compared to regular ventilation cooling (Kaukoranta et al 2012). Droplets cool down the climate without releasing CO_2 out of the greenhouse while balancing the relative humidity within the greenhouse. All these factors contribute to better yields compared to flow-through ventilation cooling.

7.1.4 Thermal Batteries

Water containers, such as fish tanks and sump tanks, can be partially buried underground or covered with soil to insulate them as thermal batteries. Also large ground masses can be used as thermal batteries. Excess heat is either stored or taken from a big mass of matter by a controlled circulation of a refrigerant liquid in an installed pipeline. This assists in stabilizing the thermal conditions within the facilities. Big masses of water have high specific heat capacity that assists them in keeping the temperature balanced between day and night temperature variations.

Water storage tanks are easier to heat up than to cool down. It is essential to block direct sunlight from entering the water storages during the warm season. It is reasonable to place the water storage tanks either inside or outside the northern wall of the structure. This is done to prevent overheating and growth of algae in the tank during the summer. Solar irradiation reflecting surface materials are recommended for the outside of the tanks during the summer. Good insulation material in the tank reduces undesired heat transfer during warm or cold hours of the day.

Ground heat pumps can be operated to cool down the water mass in the summer time and storage thermal energy from the oven, electric heaters, solar heaters and heat exchangers during the winter. Around 10 liters of water is a sufficient heat storage during the winter time in 63-degree latitude for each cubic meter of air in a greenhouse (Lampinen 2015). According to this recommendation the ratio between water and air volume in the system should be 1:100.

7.1.5 Passive Solar Heating

Passive solar greenhouse technology may be used to reduce the need for energy for cooling and heating purposes. Impacts of passive solar greenhouse technology on aquaponics maintenance work flow is yet to be evaluated sufficiently. Optimal southern transparent wall angle of 70 degrees is used to trap solar radiation during the winter and block excess radiation during the summer.

The required area for commercial scale passive solar greenhouses is very large, since the thermal mass storages take significant amounts of space. The overall size of a single passive solar greenhouse is limited due to the shape of the structure. Commercial systems need to be consisted of multiple smaller passive solar greenhouse units that might still share the same air and water circulation.

The decision of whether to install a solid well insulated roof or a transparent less insulating surface has to be made when the greenhouse is designed and constructed. Large transparent surfaces let the greenhouse to better utilize the sunlight but causes challenges when it comes to efficient insulation. Also snow during the winter time might prevent the benefits of transparency. Solid roof insulation saves heating energy costs during the winter season (Myntti, 2009).

Polycarbonate is a technical plastic that is very durable, shockproof, UV-resistant, well insulating and let solar irradiation penetrate well. It is also fire resistant and its expected life span can be up to 12 years. These qualities make polycarbonate an excellent choice for the greenhouse’s transparent surfaces (Edvards 2013).

7.1.6 Solar Energy

Solar thermal heaters can be utilized to collect and channel thermal energy of solar irradiation into the greenhouses or water tanks. Solar thermal collectors have a good efficiency rate due to low loss from energy transformation and transmission. Solar thermal energy can be stored in the greenhouse air or in the water circuit during the winter or in the thermal mass for long-term storage during the summer.

In Finland ready calculation methods can be utilized to calculate sufficient solar thermal heating capacity for the facility (Heimonen 2011).

In photovoltaic systems current price structure does not make the solar electricity systems economically viable, since the ROI can extend up to 40 years, which is more than the average lifetime of the PV equipment (Räsänen 2015). Industries receive currently very little financial incentives to invest into solar electricity.

7.1.7 Pellet Oven Heating

Heat and CO_2 for greenhouse are generated in the pellet stoves. Wood pellets are being combusted in the ovens to release thermal heat efficiently. Exhaust is filtered and CO_2 is released into the greenhouse. This accumulates both heat and CO_2 in the greenhouse.

Ovens can combust chipped peat (1.4 MWh/m3), wood chips (0.8 MWh/m3) or wood pellets (4.7 MWh/ton) of which wood pellets are recommended. This is due to very slow renewability rate of peat products and because wood pellets have much higher combustion efficiency than wood chips (Suomen Bioenergiayhdistys ry, 2002).

Lepaa HAMK is testing pellet oven heating for greenhouse production during the writing of this thesis.

7.1.8 Biogas Combined Power and Heating

To further close the input and output loops of aquaponics systems, biogas systems can be integrated into aquaponics to generate part of the energy required to maintain the processes. Waste such as plant-residues, filtered sludge, food waste and other nearby municipality and agriculture organic waste in addition to forestry biomass can be used to feed combined heat and power units (CHP) which may provide electricity and heating gas for the aquaponics processes.

In the aquaponics facility that utilizes CHP at least 50 tons of fish have to be bread with a hydroponic grow bed area of 800 - 900 m2. In total the minimum CHP-powered aquaponics system contains 1000 m3 water. (Gigliona 2015). The exhaust CO_2 from biomass and biogas combustion may also be utilized within the greenhouses to increase plant growth.

TABLE 7. Methane yield and water content of the organic substances fermented in the digester (FNR, 2010, p. 85).

Substance	**Methane yield [m3 /kg Wet Weight]**	**Water**	**Methane yield [m3 /kg Dry Weight]**
Fish Waste *	0.157	70.1%	0.525
Plant Residues *	0.105	88%	0.875
Food Waste	0.061	85%	0.321
Average	0.108	81%	0.573

* = Feed produced by the aquaponics facility operations

8 ZOOLOGICAL RISKS

A multi-trophic system such as aquaponics has a vast range of biological challenges. From fish diseases and viruses to plant pests, fungi and anaerobic bacteria, many unexpected events may occur if the facility designers and managers have not taken into account the biological side of risk management. This section describes some of the most common biologic risks in Finland related to aquaponics.

A more general aquaponics table of risks listed during the E-Fishient project can be found in the Appendix 4.

8.1 Fish Diseases

Diseases can cause major losses in aquaponics production. Since the plant production is dependent on the well balanced amount of healthy well-eating fish, a disease outbreak can significantly reduce the production of both fish and plants in the system. Plant production can be compensated by adding synthetic fertilizers to the plants but the increased input cost of chemicals and the reduced fish production will still have a notable impact in the profitability during disease outbreaks. Evira monitors the fish disease situation in Finland on a regular basis. The following summaries are from Evira fish health seminar from the year 2012 (Evira 2012).

Flavobacterium psychrophilum

Flavobacterium psuchrophilum is the most common fish disease in Finnish inland aquaculture facilities. Infections have been identified within all age groups but treatment mostly needed only among 0 to 1-year old age group of farmed fish. Infections have been identified 43 times within the 25 operational inland aquaculture facilities. 60% of the infections have been identified within rainbow trout populations and the rest among, salmon, trout, whitefish, arctic charr, sheefish and grayling (Vennerström 2011).

Aeromonas salmonicida

Different strains of Aeromonas salmonicida have been identified 9 times in 6 different inland aquaculture facilities. Immunosuppressed infected fish have a high mortality rate up to 73% (Bullock et al 1975).

Yersinia ruckeri

Yersinia ruckeri was identified 9 times in 4 different inland aquaculture facilities. The strain B1 is the only one in this category that has been identified in inland production facilities. Vaccinations usually work well against the disease but might fail due to high vaccination or environmental stress suffered by fish.

Candidatus arthromitus - Rainbow Trout Gastroenteritis

A new bacteria first time identified in Finland in 2010, causing low absorbance of nutrients from the feed to the fish tissues. This bacteria stream is not well known or researched yet, but it is estimated that this stream is naturally present within the digestion system of many fish species and the disease symptoms occur when the bacteria levels grow into extraordinary high levels in the organ *pyloric caeca* due to yet unknown reasons. Bacteria level growth results to exposure of vast areas of lamina propria; most likely resulting in the disturbance of the host animal's osmotic balance which leads to the entry of secondary pathogens into the vital organs (Del-Pozo et al 2010).

Renibacterium salmoninarum

Renibacterium salmoninarum causes slowly developing BKD disease that causes chronic problems within the fish digestion system. Its symptoms are lowered feed intake rate, swimming disabilities, anemia and low mortality. BKD disease has been identified 7 times in 4 inland aquaculture facilities.

8.2 Fish Parasites

A range of parasite species has been identified to cause significant reduction in the growth rates of fish and increase the fish mortality. The following species should be further studied to identify the potential growth constrain causes within the aquaponics facility: *Sessile Ciliates, Motile Ciliates, Dinoflagellates, Coccidia, Microsporidians, Myxozoans, Monogeneans, Digenean Trematodes, Nematodes, Acanthocephalans, Cestodes, Leeches, Pentastomes & Crustaceans* (Deborah et al 2014)

8.3 Plant Diseases and Pests

Insects, fungi and mold species have the potential to destroy whole plant harvests if not managed properly. Common plant diseases in Finnish greenhouses are *Botrytis cinerea, Phytophtora cactorum* and viruses. Common pest species in Finnish greenhouses are *Tetranychus urticae, Trialeurodes Vaporariorum, Ortiorynchus.* Since the range of different pest species is so vast and varies in different regions, this section is not inspected in the sufficient length in this paper. It is still in vital importance to be aware of the potential pest risks in the area where the aquaponics facility is being constructed. Mapping the available pest control solutions in good time is to be done to have sufficient budget allocations and expertise available in case of a pest infestation.

Cold climate reduces the amount of naturally occurring pests in Finland by reducing the multiplication and spreading of the species. Especially species that cannot tolerate the freezing winter conditions cannot spread effectively within the Finnish boarders. Cold climate also reduces the growth rate of microbiological colonies and prevents many of the parasitical species from surviving over the winter. For these reasons the requirements for pesticides, herbicides and fungicides in Finland is lower than the global average (ETL 2009).

Since the organisms within aquaponics usually share the same water in circulation, usage of toxic pesticides and fungicides is not recommended. Especially fish fingerlings in the system may suffer serious health damages from added pesticides. For this reason, other methods of integrated pest management have to be utilized in the hydroponic systems.

Covering the cultivation facilities with UV-reflecting film reduces the capability of navigation for many types of pests (Shimonda et al 2013). Utilizing artificial UV light sources with electrical traps can be used to illuminate the plants, trap the pests and feed them to the fish in the aquaculture section.

Pesticides are also needed in aquaculture greenhouses to avoid pest outbreaks from destroying the crops. It is recommended to use multiple different as little toxic pesticides as possible, to prevent the pests from building up a resistance against a single pesticide product. It is important to use fish-friendly chemicals in as small quantities as possible to avoid causing health damage to the fingerlings.

9 LEGAL REQUIREMENTS FOR AQUAPONICS IN FINLAND

There is a range of legislation controlling and adjusting both greenhouse cultivation and aquaculture. In aquaponics both of these sets of laws have to be taken into consideration when planning, building and maintaining aquaponics operations. Especially aquaculture component brings in a large sets of legislation from water and nature conservation laws to legislation around animal rights and disease control. Aquaculture is the only form of primary production in Finland that requires environmental permits to be obtained before legally operating the facilities.

9.1 Environmental Permits

Aquaculture is the only primary production value chain that requires environmental permits for operations. For example, cattle industry or traditional agriculture practices do not require environmental permits; even though their overall contributions to the eutrophication of Finnish lakes and in the Baltic Sea is many times higher according to the latest statistics from the national VAHTI-recording system and Finnish Environment Institute (SYKE 2015).

Majority of the water phosphorus and nitrogen burden comes currently from agriculture. Agriculture contributes to 56.8% of phosphorus inputs and 46.5% of nitrogen inputs into water sources. Aquaculture contributes around 2% of phosphorus burden and 0.9% of nitrogen burden (VAHTI 2015). Fish production generates 58 million kg food products and other agriculture generates 12819 million kg of food (Niemi et al 2014). In this light the nutrient burden of natural waters from traditional aquaculture per kg of food produced is nearly 5.5 times higher than of traditional agriculture.

Even though the nutritional levels in fish produce are very high the production's environmental impacts are in unsustainable levels. Improvements in RAS and Aquaponics production systems may provide resource-efficient solutions.

A list of relevant national legislation can be found in Appendix 3.

10 AQUAPONICS ECONOMIC VARIABLES IN FINLAND

One way to compare the economic benefits of aquaponics is to compare the system with a separate RAS and hydroponic greenhouse systems and calculate the benefits the synergy provides. This has been done only once and the research concluded that the integration of RAS and hydroponic greenhouse technologies could improve the overall profitability by 4,2% (Rupasinghe et al 2010).

In this short simulation the greenhouse production models are roughly divided into two and aquaculture models into three categories in the next comparison. The cucumber greenhouse operates year around with artificial lighting and the tomato greenhouse operates without artificial lights 6 months per year. Investment cost for the year around cucumber greenhouse is around €150k and for the extended thermic period tomato greenhouse €50k.

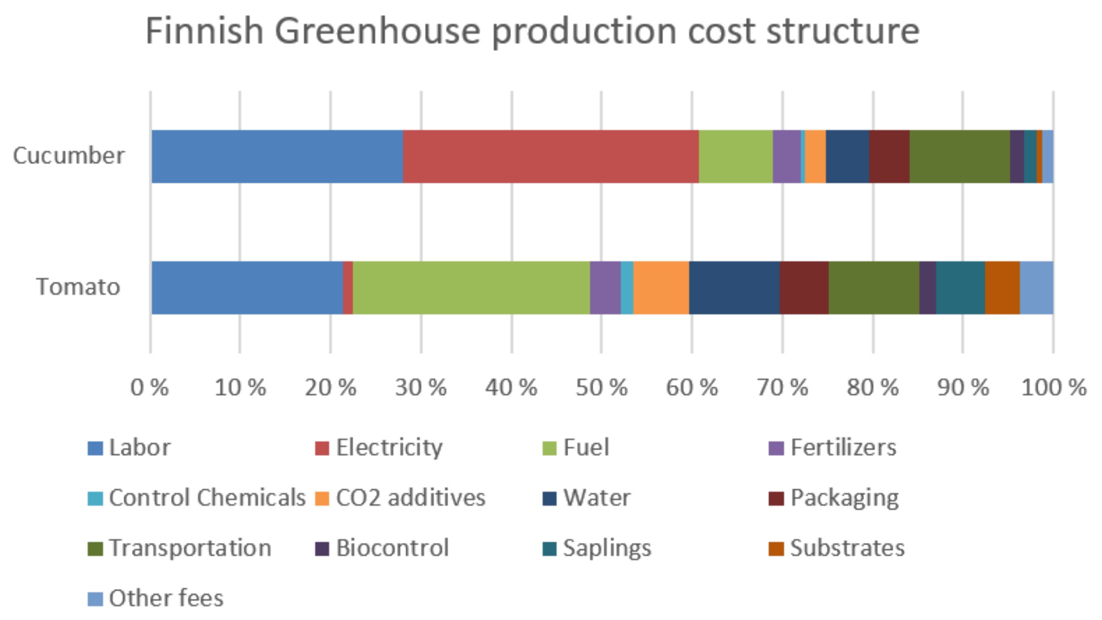

FIGURE 10. Finnish Greenhouse Production cost structure (Based on Österman 2001, Parikka 2003, Outa 2000, Energiamarkkinavirasto 2003, Öljy- ja kaasualan keskusliitto 2003, Kauppapuutarhaliitto 2003, Maaseudun työnantajaliitto 2003)

Aquaculture is most commonly done in net cages, RAS facilities or flow through systems. Figure 14 compares the cost structures of these different methods.

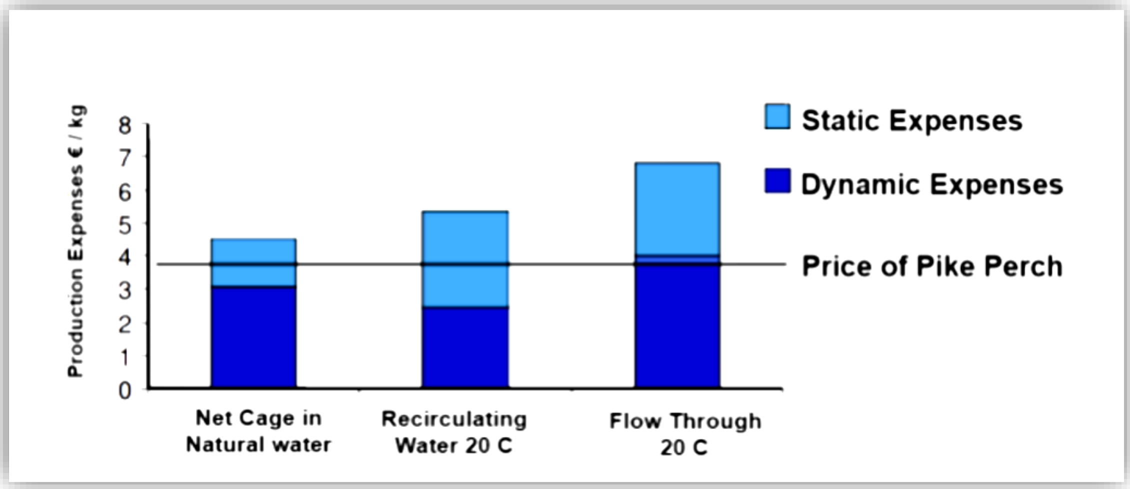

FIGURE 11. *Sander lucioperca* production costs (Statistics: Koskela 2006)

Ready budget simulators for Finnish aquaculture have been built by LUKE and they are freely available online (Korhonen 2009).

In a recent survey from Love et al cost analysis was conducted between different aquaponics growing facilities. Interviewed 1084 survey participants were from 23 different countries, mostly from the United States of America. According to the answer results aquaponics businesses in mild winter condition areas were four times as likely to be profitable compared to the businesses operating in cold or very cold winter conditions (Love et al 2015).

This indicates that the temperature and light conditions in the northern regions pose extra challenges for making aquaponics operations profitable (Love et al 2015). This is why cost-effective temperature control and artificial light technologies are in high priority when aquaponics based businesses are designed in Finland (Särkkä et al 2008).
Initial costs in closed-loop aquaponics is relatively high. As a comparison number, average cost for sea-based fish growing operations in Finland is €2M and in land-based fish growing operations five times more, €10M (Laitinen 2014).

10.1 Potential Impact of Political Decisions on Fish Market Prices in Finland

Fish is recommended to be eaten at least twice a week by the Finnish Health Authorities. Exceptions are provided by the polluted state of many natural water bodies such as the Baltic Sea, where it is not recommended to eat fish from at all due to the high levels of dioxins, PCB, methyl mercury and cesium-137 compounds (Evira 2015). This indicates that there is an official consensus for recommending improved and toxin-free production and consumption of fish.

Vesiviljely 2022 strategy paper formulated strategies how Finnish fish production could be tripled between the year 2014 and 2022 (Vesiviljely 2022). These measures may affect the market prices through increased subsidies or lowered taxes, which increase the production incentives and potentially lower the market prices for produce.

Legislation on national and EU level have a significant impact on the profitability of aquaponics. Depending on what kind of production methods and facilities receive public subsidies can have crucial impact on the market conditions and the profitability of aquaponics production facilities. Without subsidies towards RAS systems and without tighter waste management regulation for open sea based aquaculture, aquaponics is not likely to be competitive without very specialized products and business models.

10.2 Market Prices of Vegetable Products

Between 1998 and 2008 the consumption of fresh vegetables per capita in Finland grew 19% from 47.1 kg to 56.2 kg per year. Total procurements of greenhouse produced vegetables grew 27% from 72 000 tons to 91 000 tons (Pesola et al 2012).

Finland has an oversupply of conventional cucumber production lowering the produce prices, undersupply of organic cucumber production due to challenges with incompatible organic fertilizers and tomato demand shifting from conventional produce to special types of tomatoes. High demand on organic Finnish cucumber poses great potential for aquaponics production if the process can be organically certified. Finnish leek and paprika with other exotic root vegetables would have year-around demand (Pesola et al 2012).

Repetitively reducing production prices of traditional cucumber and tomato during the last few years has created pressure for new types of production processes and products to be introduced to the markets (Maaseudun Tulevaisuus 2015).

Greenhouses that exceed the size of 300 m2 and cultivate tomato, cucumber, lettuce, Chinese cabbage, parsley, dill, paprika, cut flowers or potted plants can receive economic support for greenhouse activities from the municipal ELY-centers. Total public sector funding for agriculture activities in Finland is annually around 2.1 billion euros, which represents around ⅓ of the total six-billion-euro income in the sector.

10.3 Brand Values

Special production conditions, credible quality control systems and good reputation can increase the value of the products. This section takes a look at factors that could be considered as added values in Finnish aquaponics.

10.3.1 Finnish Brand Value

A survey conducted in 2014 for 2801 participants revealed that 60% of Finnish people check the country of origin in of food products in the grocery store. 66% of Finnish people prefer buying Finnish food. This is especially important for women above 65 years old and least important for men under 25. (Taloustutkimus Oy, 2014).

Nordic food has good reputation within markets such as Russia and other wealthier Asian countries. Comparatively high labor costs in Nordic countries and trade customs between trading areas increase the export costs. High end markets show signs of opening for clean Nordic aquaponics produce. Also markets in Sweden and Central Europe are interested about food purity and exotic tastes, where Nordic goods could have competitive advantage (Pesola et al 2012).

WWF has given a green certificate for fish produced in Finland and has stated that it would be desirable to see Finnish fish production to increase. Yet no legislation or subsidy structure support this. Imported fish production responsibility cannot be as efficiently monitored as local production (WWF 2014).

Finland has relatively clean environment and low rates of pests and low need for toxic compounds in food production, which can be utilized to further increase the brand value of Finnish food products.

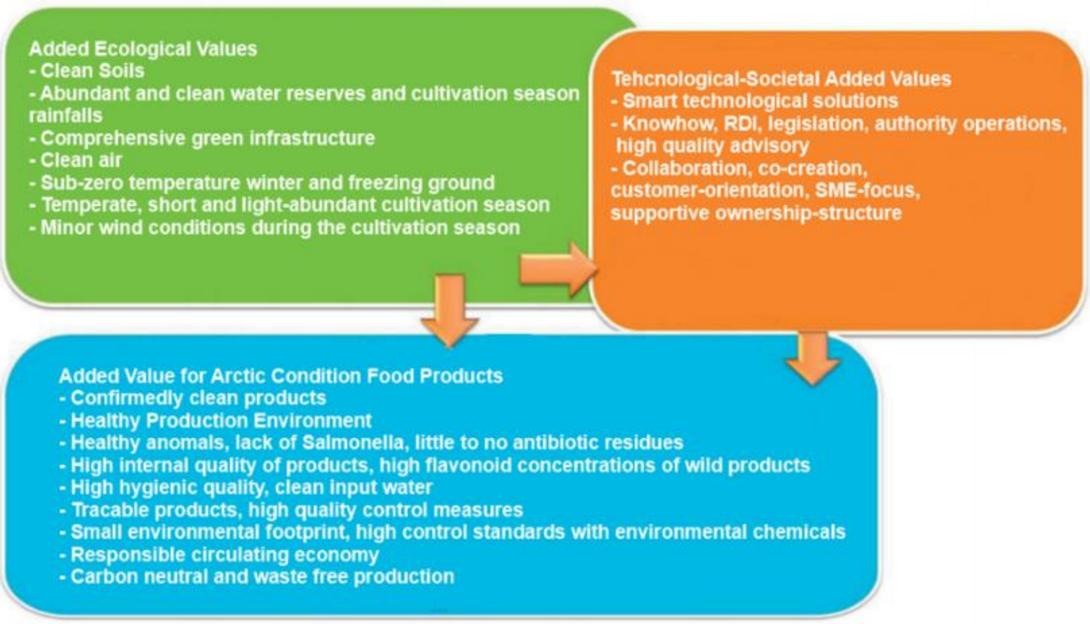

FIGURE 12. Benefits of High Performance Arctic Production
(Based on Kurppa et al 2015)

10.3.2 Organic Certification for Aquaponics Vegetable Products

Unfortunately, the EU legislation currently prohibits organic certifications for soilless cultivation methods of plants [EU 889:2008]. Since the studied aquaponics systems require soilless hydroponic systems to be integrated, the produced vegetables cannot be organically certified. The produced fish could be certified organically, but it has not been yet done in Finland.

There is very little information about the legal status of aquaculture discharge water as an organic fertilizer in organic agriculture. Aquaculture discharge water is not found from the list of nationally accepted organic fertilizers (Evira 2015).

10.3.3 Organic Certifications for Aquaponics Fish Products

In Finland there is no organic certified fish production. This might be partly because the EU legislation for organically certified aquaculture [EU 710:2009] is relatively freshly made in 2007. The wicked problem for developing the organic value chain occurs because the Recirculating Aquaculture Systems (RAS) in conjunction with hydroponics cannot receive organic-certification, even if their nutrient discharge is in the lowest level; and partly because organic certification of fish production would require organically produced fingerlings and organically produced feed; which are not in demand, since the organic fish production plants have not been officially certified yet. Starting the production of organically produced fish feed and fingerlings would cause economic losses for the organic input producers in the beginning, before the fish production facilities would be certified as organic and they would start utilizing the organic inputs. To fill the gap, European Maritime and Fisheries Fund (EMFF) could be utilized to cover the losses of organic input producers in the starting phase.

Jouni Vielma from LUKE tells that EU certification for organic feed is especially problematic since it requires at maximum 60% of the feed to consist of vegetable based products. This means that 40% of the organically certified fish feed should consist of fish-based products, which are more expensive and contain more nutrients than the fish can absorb in their tissues (Airaksinen 2012). Feed research has developed more resource efficient and environmentally friendly fish feeds that have a higher ratio of vegetable based ingredients. These feeds cannot be currently utilized in organically certified aquaculture (EU 1358/2014).

Environmental permits limit the amount of nitrogen and phosphorus the aquaculture facilities can buy in. These permits lower the annual amount of feeds that organically certified fish production facilities can purchase, reducing their production rates when using high fish-meal ratio consisting; thus high phosphorus containing; organic certified fish feeds. Organic certification does not take into account the efficiency of waste water management. Also the fish stocking density has to be lower in organic certified fish production plants.

10.3.4 Educational and Recreational Value

34% of the globally interviewed businesses were selling only plants and fish as their business. 32% of the respondents were selling only products and services related to aquaponics and 34% of the respondents were selling food products, services and materials. Clearly most profitable of these groups was the group that had diversified their income model to cover fish, plants, materials and services related to aquaponics (Love et al 2015).

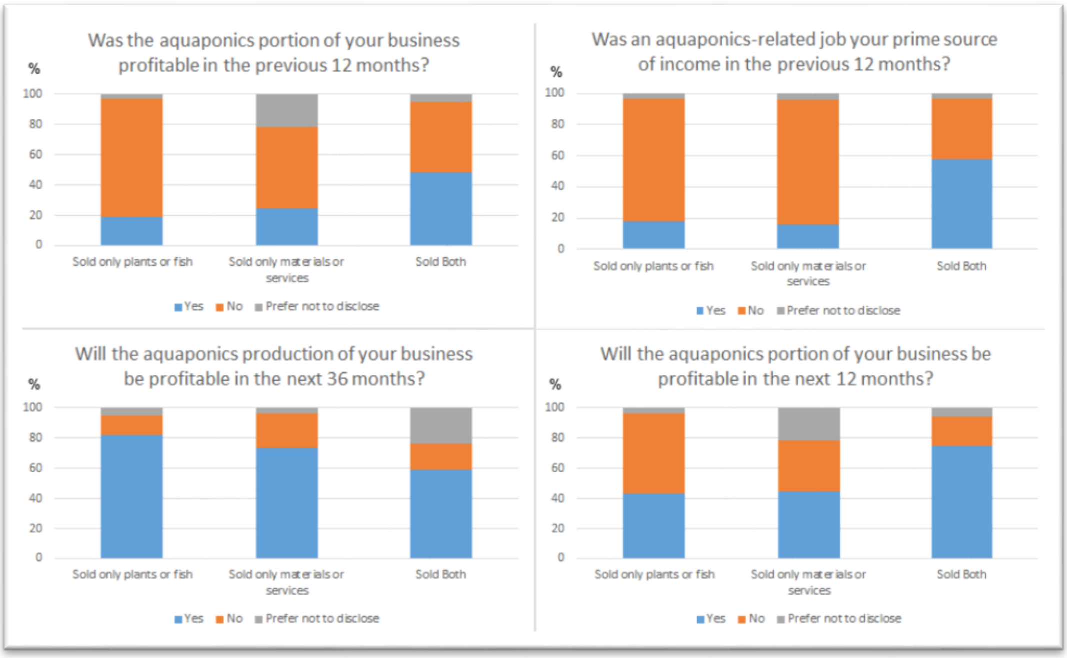

FIGURE 13. Survey results about different aquaponics business model profitability (Data from Love et al 2015)

These statistics indicate that at the moment aquaponics businesses that provide material sourcing, design expertise, consultancy, educational and recreational services have the highest business potential (Love et al 2015). That is why these elements should be designed within the aquaponics business models when establishing new operations in this field.

11 RESULTS

Vast amounts of aquaponics related research and theoretical description has been made around the world during the past 30 years. Due to the multidisciplinary nature of the method it is currently challenging to find the relevant recommendations for a certain kind of production condition, such as Finland. By combining data about the location specific weather, regional food markets and input suppliers and by comparing these results to common aquaponics principles, key bottle necks and cost factors in the processes can be identified.

Finland has competitive advantages through the availability of large amounts of public research and data. Various governmental bodies and academic institutes are collecting and processing comprehensive amounts of field data about environment and market conditions. This allows the aquaponics designers to access to the majority of the necessary information for free.

Estimated total costs for a commercial scale aquaponics facility in Finland can be estimated to reach around €10M due to the complexity, heavy bureaucratic processes and environmental impact management measures needed for operations of a large scale unit. The startup phase of the plant requires operational capital for three to four months, which it takes to build up a safe and strong bacterial foundation within the process water circulation system, especially in cold water systems.

Piloting the system gave good insight about the importance of stabile conditions and a comprehensive list of components required for aquaponics facilities. Pilot system is functional and usable for further research conduction.

According to the E-Fishient pilot observations and the literature research results Finland has pros and cons when it comes to aquaponics production. The cold and dark winter conditions require high energy consumption in year around operating facilities. Most efficient thermal control systems require moderately high electricity consumption during the summer.

The required electricity, heat and fuels for Finnish aquaponics can be produced locally without the combustion of fossil fuels. Renewables are not yet financially profitable with the current subsidy and tax structures, but it is very possible that the fossil fuel industry may not be much longer able to externalize the costs of environmental impacts that the emissions have. Realization of this in the public and political domain may significantly affect the prices of fossil fuels.

Finnish climate restricts the amount of naturally occurring bacteria, virus, fungi and parasites harmful for the aquaponics systems, thus lowering the contamination risks. The publicly supported value chains in feed, fingerling, energy and greenhouse production increase the quality and secure availability of production inputs.

Based on the discussions and documents the legal requirements and environmental permits are stricter for inland aquaculture and aquaponics than for the ocean aquaculture production units. Building permit, food safety, environment and animal rights related legislation require various quality control mechanisms to take place within the whole value chain of aquaponics production. This provides stability and risk management for the operations, also generating costs that have to be factored in to the business plans.

Aquaponics development is dependent on the production efficiency development steps in RAS aquaculture, RAS sludge fertilizer production and hydroponic greenhouses. In the near future the RAS systems may be made profitable and if the effluent sludge can be formulated to be an efficient source of hydroponic nutrients, it can further advance the development of aquaponics value chains.

Aquaponics profitability depends on the capabilities of the aquaponics companies to design, construct and maintain resilient and site-adaptive aquaponics facilities. Another important profitability factor is the ability of the companies to build functioning business linkages to the high value, locally oriented and quality aware markets. Food products with local branding have a slight market advantage in Finland according to the publicly available consumer survey material.

The organic certification system for aquaponics produce has not yet been fully established in the EU or Finland. The Finnish national policies limit the development of organic aquaponics by limiting the fish feed consumption in organically certified facilities. The current EU organic aquaculture legislation prohibits the use of mainly plant-based feeds in organically certified aquaculture facilities. Updated aquaponics legislation in the EU and on national level could significantly increase the profitability and efficiency of aquaponics in Finland.

Increased energy efficiency of aquaponics facilities, increased cost-efficiency of fish feed manufacturing, monitoring automation, improved facility workflow, increase in production rates and production of fertilizers from the excess sludge are the main fields of improvement in the field of aquaponics to make it commercially viable in Finland.

12 DISCUSSION

The E-Fishient research pilot project assisted a lot in understanding the complex inter-linkages between the different physical, chemical and biological reactions within the aquaponics system.

The research managed to compile relevant statistics and information about the special requirements for aquaponics in Finland. Even though the list of requirements might not be complete, it covers many of the main aspects aquaponics production facility designers in Finland should cover during planning.

Aquaponics facilities are multidisciplinary ecosystems and due to the diverse nature of the research setups and lack of international standards, many of the current research results are not easily comparable with each other. This challenge is wise to take into consideration if further researching the topic.

The labor costs for aquaponics systems in Finland can be lowered with automation. Technology exists to automate water sampling, fish feeding and most of system cleaning. Automation can be done with industrial equipment or through utilization of Open Source hardware and software solutions. Durable controllers, submersible UV/vis spectroscopes and industrial size pumps are recommended in large scale operations due to their accuracy and durability. Open source tools and other less costly sensor systems are fit for smaller research projects and experimental production setups. Sundgren successfully reproduced a small open source automation system for hydroponics and reported the process in his Bachelor's Thesis (Sundgren 2015). By replacing the nutrient solution pump controllers with the pellet feeder screw controllers the same setup should work in micro scale aquaponics.

Improving material science solutions such as energy efficient & transparent insulation, transparent photovoltaics and artificial lighting increase the cost-effectiveness of the production systems. Fields of improvements can also be found in the water sensor industry. Currently robust submersible UV/vis spectrometers that are recommended for the measurements cost up to € 30 000 which limits the availability of otherwise affordable and reliable automation solutions. Further development of open source software and hardware, such as Linux and Arduino reduce the manufacturing costs of site-adaptive automation systems.

Globally important aspect of aquaponics research is to find out how to improve the efficiency of RAS filters in the accumulation of nutrients from the circulating water and how to process these nutrients effectively to make them optimally absorbed within hydroponic systems.

A wider catalogue of aquaponics services within the production facilities including educational, recreational and consultancy services improve the profitability rate among aquaponics entrepreneurs.

Change in the EU legislation to allow the more resource-efficient plant-based fish feeds to replace the mainly fishmeal-based feeds in organic aquaculture would improve the conditions for organic aquaponics in Finland. On national level, basing the environmental permits on the discharge water nutrient concentration instead of the feed input in the facilities would create incentives for the aquaculture facilities to improve their waste water management. At the moment the restrictions only restrict, but do not create incentives or possibilities for the industry to improve its resource-efficiency.

Finnish inland aquaponics production is not at the moment cost competitive with Norwegian salmon production. Finnish aquaponics may still be very quality competitive and an attracting option in the quality aware markets.

Closest alternative food production methods for aquaponics are improved waste water management in aquaculture, scaling up the natural lake fish production and developing renewable nutrient sources for hydroponics. All of these alternatives are viable food production methods in Finland.

13 CONCLUSION

According to the obtained research materials aquaponics has not yet been established as a profitable operation within the Nordic countries. Theoretical studies predict that aquaponics can be made profitable in the region with improved design of systems, workflow, materials and chosen species. Basing the designs on Recirculating Aquaculture Systems (RAS) currently under development could bring the aquaponics into profitable practice within a decade. To reach a new level of integrated greenhouse aquaculture, further collaboration between greenhouse entrepreneurs, aquaculture entrepreneurs and chemical research institutes would be required. Product development and manufacturing of RAS sludge hydroponic fertilizer solution could be a start of new relationship. Suitable solutions for tomato, cucumber, lettuce and most common herbs would be valuable since they are the most commonly produced hydroponic vegetables in Finland.

Multiple cost-effective energy utilization methods such as utilization of optimal structural design, well insulating materials, heat exchange, ground heat, external process energy, biogas CHP, droplet cooling, thermal batteries and solar energy collectors can reduce the energy consumption costs of aquaponics facilities or its individual components.

Legislation changes in the EU and Finnish laws could increase the incentives for more resource-efficient and up-scaled production. Allowing the use of plant-based fish feeds in organic aquaculture, limiting the aquaculture environmental permits based on the effluent water quality and quantity instead of the amount of input feed and; creating clear organic aquaponics legislation would each assist in upscaling the organic Finnish aquaponics production.

Aquaponics projects should be planned according to the following key principles;

1. Choosing produced species according to the target market demands
2. Designing facilities according to species and the regional special requirements
3. Choosing cheapest reliable inputs according to the system demands
4. Designing good workflow for hydroponics, aquaculture and lab work
5. Designing the facility to be easily maintainable and scalable in later phases

Aquaponics in Finland can be profitable with the right market response and suitable technology choices. Scientifically aligned legislation could increase the production potential of aquaponics systems.

REFERENCES

Airaksinen S., Kankainen M. , Suomela J.-P., Sandell M. & Kiviranta H., 2012. Kirjolohen räätälöinti jalostuksen ja kuluttajan tarpeita vastaavaksi, Riista- Ja Kalatalouden Tutkimuslaitos, ISBN 978-951-776-940-2

Alleman J. E., Keramida V., Pantea-Kiser L., 1987. Light Induced Nitrosomonas Inhibition, Water Research; Volume 21, Issue 4, Elsevier Ltd, April 1987, Pages 499–501

Anderson J., 2010. Led-Valaistus Kasvihuoneisiin, Aalto Yliopisto Teknillinen Korkeakoulu, Elektroniikan, Tietoliikenteen Ja Automaation Tiedekunta Elektroniikan Laitos, Valaistusyksikkö

Arteca R. N. 2015. Introduction To Horticultural Science, Stamford

Asao T., 2012. Standard Methodology For Plant Biological Researches, ISBN 978-953-51-0386-8, 254 Pages, Publisher: Intecha

Ash T., 2014. Neoarcology: True Sustainability Through The Application Of Permaculture, Aquaponics And Arcology, Independent Publication

Blidariu F., Grozea A., 2011. Increasing The Economical Efficiency And Sustainability Of Indoor Fish Farming By Means Of Aquaponics. Banat's University Of Agricultural Sciences And Veterinary Medicine, Faculty Of Animal Science And Biotechnologies, Romania

Bugbee B., 2015. Vertical Farming – Turning Fossil Fuels Into Food, Department Of Plants, Soils And Climate, Utah State University. Available At Https://Usu.App.Box.Com/S/6t2qfa3xng2bb4rpa2536lg4yrqf4sug , Referred 02.01.2015

Bullock & Stuckly H. 1975. Aeromonas Salmonicida Detection Of Asymptomatically Infected Trout. The Progressive Fish-Culturist. 37, 237-239

Del-Pozo J., Crumlish M., Turnbull J.F., Ferguson Hw. 2010. Histopathology And Ultrastructure Of Segmented Filamentous Bacteria-Associated Rainbow Trout Gastroenteritis. Institute Of Aquaculture, University Of Stirling, Uk

Edvards A. 2013. Abe's Guide To The Greenhouse, Smashwords Edition

El-Saye A.-F. M., 2006. Tilapia Culture, Alexandria University, Oceanography Department, Cabi Publishing

Etl (Elintarviketeollisuusliitto). 2009. Lihantuotannon hyvät toimintatavat – Sikaketju. Elintarviketeollisuusliitto Ry, Suomen Lihateollisuusyhdistys. Viitattu 09.01.2016. Available At: Http://Www.Etl.Fi/Media/Aineistot/Suositukset-Ja-Ohjeet/Hyvat_Tuotantotavat_Sika.Pdf

Evira, Kalaterveyspäivät 28.03.2012. Luentokokoelma, Elintarvikevirasto Evira, Available At: Http://Www.Evira.Fi/Files/Attachments/Fi/Elaimet/Elainten_Terveys_Ja_Elaintaudit/Terveydenhuolto/Kalat_Ja_Ravut/Kalaterveyspaiva_2012_Web_200312.Pdf

Fao, 2012. State Of The World Fisheries. Rome.

Fnr, 2010. Leitfaden Biogas - Von Der Gewinnung Bis Zur Nutzung. 5 Ed. Gülzow: Fachagentur Nachwachsende Rohstoffe E. V. (Fnr)
.
Gerardi M. H., 2006. Wastewater Bacteria, Water Pollution Biology, Williamsport, Pennsylvania. Wiley.

Gigliona J., 2015. Implementation Of A Biogas-System Into Aquaponics : Determination Of Minimum Size Of Aquaponics And Costs Per Kwh Of The Produced Energy, Mid Sweden University

Goddek S., Delaide B., Mankasingh U., Ragnarsdottir K.V., Jijakli H., Thorarinsdottir R., 2015. Challenges Of Sustainable And Commercial Aquaponics - Open Access Sustainability

Heimonen, I., 2011. Aurinkolämmön Ja –Sähkön Energiantuoton Laskennan Opas, Vtt

Hooper A. B., Terry K. R., 1974. Photoinactivation Of Ammonia Oxidation In Nitrosomonas, Journal Of Bacteriology 1974 Sep; 119(3): 899–906.

Ivanić J., Havelka, B., Knop K., 1984. Nutrition And Fertilization Of Plants. Príroda: Bratislava – Szn Praha. Pp. 488

Jenkins, D. 2008. Kasvuvalo. Teoksessa Piirainen, J. (Toim.) Puutarhakalenteri 2008. S. 190–193.

Kaukoranta T., Näkkilä, J., Särkkä L., Jokinen K., 2012. Energian Käytön Ja Kasvihuonekaasujen Vähentämisen Potentiaali Kasvihuonetuotannossa, Mtt

Kaukoranta T., Näkkilä J., Särkkä L., Jokinen K., 2014. Effects Of Lighting, Semi-Closed Greenhouse And Split-Root Fertigation On Energy Use And Co2 Emissions In High Latitude Cucumber Growing, Mtt Agrifood Research Finland, Piikkiö, Finland

Keitaanpää T., 2011. Kannattavuuteen Vaikuttavat Tekijät Suljetun Kierron Kaupallisessa Vihanneskasvihuoneessa, Hämeen Ammattikorkeakoulu, Ympäristöteknologian Koulutusohjelma

Kurppa S., Kotro J., Heikkilä L., Reinikainen A., Timonen K., Peltola R., Manninen O., 2015. Arktinen Ruoantuotanto - Taustaselvitys Ja Kiteytysmatriisi, Luonnonvara- Ja Biotalouden Tutkimus 47/2015

Korhonen P., 2009. Kalankasvatuksen Kannattavuuslaskentaohjelma V.0.998. Riista- Ja Kalatalouden Tutkimuslaitos 2009.
Program Download Page: Http://Www.Riistakala.Info/Vilmal/Lataus.Php

Koskela J., 2006. Uusilla Lajeilla Mahdollisuuksia Kalankasvatuksessa, Riistan- Ja Kalantutkimuslaitos, Tutkimuspäivät Kuopio 22-23-11-2006

Laitinen A., 2014. Suomessa Kasvanut Kala, Suomen Kalankasvattajaliitto 2014, Finland

Lampinen J-M., 2015. Aurinkokasvihuone; Toimintaperusteet Ja Rakennusmallin Suunnittelu, Savonia Ammattikorkeakoulu, Rakennustekniikan Koulutusohjelma

Larkum, Edited By Larkum A. W. D., Douglas S. E. & Raven J. A. 2003..Photosynthesis In Algae. London: Kluwer.

Lehtonen S. 2002. Keinovalo Panee Kasvit Töihin, Maaseudun Tulevaisuus 4 (16.12.2002) 59.Vuosikerta

Love D. C., Semmens K., Fry J. P., Thompson R.E., Li X., Hill E. S., Genello L., 2015. Commercial Aquaponics Production And Profitability: Findings From An International Survey, Aquaculture 435 (2015) 67–74

Luke. 2015. Kasvihuoneyritysten Energiankulutus Vuosina 2006, 2008, 2011 Ja 2014, Luonnonvarakeskus, Available At: Http://Stat.Luke.Fi/Sites/Default/Modules/Pubdlcnt/Pubdlcnt.Php?File=Http://Stat.Luke.Fi/Sites/Default/Files/Kasvihuoneiden_Energiankulutus_2014_0.Xlsx&Nid=4362

Maaseudun Työnantajaliiton Ja Puu- Ja Erityisalojen Liiton Välinen Puutarha-Alan Työehtosopimus 1.3.2012 – 31.1.2014

Mallick F. R., 2005. Proceedings Of The International Conference & Exhibition On Soilless Culture: International Society For Horticultural Science. Commission For Plant Substrates. Icesc-2005 : Fort Canning Gallery, Singapore : September 5-8, 2005

Marshall M., 2013. Farmed Fish Overtakes Farmed Beef For First Time, New Scientist, Magazine Issue 2922, Published 22nd June 2013
Myntti A., Patenttihakemus 20095734, 2012

Niemi J. & Ahlstedt J., 2014. Suomen Maatalous Ja Maaseutuelinkeinot, Mtt – Agrifood Research Finland, Publications 115, ISBN 978-951-687-173-1

Nootong K., Powtongsook S., 2011. Performance Evaluation Of The Compact Aquaculture System Integrating Submerged Fibrous Nitrifying Biofilters, Biochemical Engineering Research Unit, Chulalongkorn University, Bangkok, Thailand

Parikka P., 2003. Kasvihuonevihannesten Taudit Ja Niiden Torjunta. Puutarha & Kauppa 7(8). S. 10-15

Pesola A., Hagström M., Tommila P., Vanhanen J., Pursula T., 2012, Liiketoimintasuunnitelma Ekotehokkaalle Kaupalliselle Kasvihuoneelle, Gaia Consulting Group

Resh H. M., 2004. Hydroponic Food Production, Newconcept Press Inc. New Jersey, ISBN 0-931231-99-X

Rakocy, J.E., Shultz, R.C., Bailey D.S. And Thoman, E.S. 2004b. Aquaponic Production Of Tilapia And Basil: Comparing A Batch And Staggered Cropping System. Acta Horticulturae (Ishs) 648:63-69.

Rakocy J. E., Bailet D. S., Schultz R. C., Danaher J. J., 1993, A Commercial-Scale Aquaponic System Developed At The University Of The Virgin Islands

Runkle E., 2011. Greenhouse Energy Conservation Strategies, Department Of Horticulture, Michigan State University And A. J. Both, Bioenvironmental Engineering, Department Of Environmental Sciences, Rutgers, The State University Of New Jersey

Rupasinghe J.W., Kennedy J. O. S., 2010. Economic Benefits Of Integrating A Hydroponic-Lettuce System Into A Barramundi Fish Production System, 04/2010; 14(2):81-96.

Räsänen J., 2015. Aurinkoenergian Hyödytäminen Kasvihuonetuotannossa, Tampereen Ammattikorkeakoulu, Sähkötekniikan Laitos

Savikko H., Mortensen D.G., 1993. Effects Of Water Temperature On Growth Of Juvenile Pink Salmon (Oncorhyncus Gorbuscha). U.S. Dep. Commer., Noaa Tech. Memo. Nmfs-Afsc-28, 12p.

Shimonda M., Honda K., 2013. Insect Reactions To Light And Its Applications, Applied Entomology And Zoology, Volume 48, Issue 4, Pp 413-421

Somerville C., Cohen M., Pantanella E., Stankus A., Lovatelli A., 2014. Small-Scale Aquaponics Food Production, Fao, Rome

Sundgren A, 2015. Open Source Automation For Hydroponics : Design, Construction, Programming And Testing, Tampere University Of Applied Sciences, Degree Programme In Environmental Engineering

Suomen Bioenergiayhdistys Ry. 2002. Bioenergia Suomessa. Energiayksikköjä Ja Muuntokertoimia. Viitattu 16.01.2016. Www.Finbioenergy.Fi/Default.Asp?Sivuid=9205

Syke, 2015. Vahti Program, Visited At 22.11.2015 Available At: Http://Www.Ymparisto.Fi/Fi-Fi/Kartat_Ja_Tilastot/Vesistojen_Ravinnekuormitus_Ja_Luonnon_Huuhtouma

Särkkä L., Luomala E-M., Hovi-Pekkanen T., Kaukoranta T., Tahvonen R., Huttunen J. & Alinikula M., 2008. Kasvihuoneen Jäähdytyksellä Parempaan Ilmastoon Ja Satoon, Mtt, Jokioinen, Tampereen Yliopistopaino

Taloustutkimus Oy, 2014. Suomi Syö 2014

Timmons M. B., Ebeling J. M., 2007, Recirculating Aquaculture, 2007, Cayuga Aqua Ventures, Northeastern Aquaculture Center, Usa

Tuomainen M., Mölsä H., 2011, Vesiviljelyn Sijainninohjaus Itä-Suomessa, Fish Innovation Center

University Of Oregon, 2007, Solar Monitoring Laboratory, Sun Path Chart Program, Visited 09.02.2016, Available At: Http://Solardat.Uoregon.Edu/Sunchartprogram.Html

Österman P., 2002, Talvitomaatin Tuotantokustannus Ja Kannattavuus, Maa- Ja Elintarviketalouden Tutkimuskeskus, ISBN 951-729-701-7

APPENDICES

Appendix 1. Greenhouse maintenance cost structure (/1000m2/a)

	Tomato* (€)	% of Total (tomato)	Cucumber** (€)	% of Total (cucumber)
Labor	9822	21,31 %	42540	27,97 %
Electricity	535	1,16 %	49946	32,84 %
Fuel	12089	26,23 %	12309	8,09 %
Fertilizers	1580	3,43 %	4682	3,08 %
Control Chemicals	650	1,41 %	788	0,52 %
CO2 additives	2800	6,07 %	3500	2,30 %
Water	4681	10,16 %	7356,8	4,84 %
Packaging	2442	5,30 %	6840	4,50 %
Transportation	4620	10,02 %	16800	11,05 %
Biocontrol	885	1,92 %	2242	1,47 %
Saplings	2501	5,43 %	2201	1,45 %
Substrates	1732	3,76 %	1040	0,68 %
Other fees	1750	3,80 %	1850	1,22 %
Total	**46091**	**100,00 %**	**152095**	**100,00 %**

* Tomato greenhouse without artificial lights, 9 months growing period
** Cucumber greenhouse with artificial lights, 12 months growing period

TABLE 7: Greenhouse production cost structure in Finland (Data combined from: Österman 2001, Parikka 2003, Outa 2000, Energiamarkkinavirasto 2003, Öljy- ja kaasu-alan keskusliitto 2003, Kauppapuutarhaliitto 2003, Maaseudun työnantajaliitto 2003)

Appendix 2. National Legislation in Finland

The following laws have to be taken into consideration when designing aquaponics operations within Finland. Some of the law texts are only available in Finnish.

Environmental Law (527/2014 : Ympäristönsuojelulaki)

Water Conservation Law (27.5.2011/587 : Vesilaki)

Waste Management Law (646/2011 : Jätelaki)

Nature Conservation Law (20.12.1996/1096 : Luonnonsuojelulaki)

Law about water and ocean conservation management (1299/2004 : Laki vesien ja merenhoidon järjestämisestä)

Water Conservation Law (1040/2006 : Laki vesienhoidon järjestämisestä)

Ocean Conservation Law (980/2011 : Laki merenhoidon järjestämisestä)

Law of the Water Conservation Areas (1303/2004 : Laki vesienhoitoalueista)

Common Area Law (18.8.1989/758 : Yhteisaluelaki)

Animal Protection Law (4.4.1996/247 : Eläinsuojelulaki)

Fishing Law (379/2015 : Kalastuslaki)

Health Protection Law (19.8.1994/763 : Terveydensuojelulaki)

Legal Requirements for Domestic Water (461/2000 : Talousveden laatuvaatimukset)

Food Product Law (13.1.2006/23 : Elintarvikelaki)

Animal Feed Law (8.2.2008/86 : Rehulaki)

Animal Disease Law (441/2013 : Eläintautilaki)

Processing Plant Food Product Law (1369/2011:Asetus laitosten elintarvikehygieniasta)

Plant Pest Control Law (27.2.1981/173 : Asetus kasvintuhoojien maahan kulkeutumisen estämiseksi)

Plant Protection Law (11.6.1982/442 : Kasviensuojelulaki)

Chemical Law (9.8.2013/599 : Kemikaalilaki)

Law of Plant Protection Chemicals (29.12.2011/1563 : Laki kasvinsuojeluaineista)

Construction and Land Usage Law (10.9.1999/895 : Maankäyttölaki)

Aquaculture Environmental Protection Guide (Ministry of Environment: Kalankasvatuksen ympäristönsuojeluohje 2013)

Aquaculture Registry: Local ELY-center

Appendix 3. Aquaponics Risk Matrix

Risk	Solutions	Sev	Lik	Total (Sev*Lik)
Fish Disease (specify)	Sulfa-treatment	4	3	12
Plant Root Rot	Aeration, low water temperature, preventing light entering the water	5	3	15
Imbalance of Flora / Fauna	Good design, sequenced harvests	4	4	16
Ethical Violations of Life	Following legislation and best practices	5	3	15
Water Temperature too High	Water replacement, thermal cooling, increased ventilation	3	3	9
Water Temperature too Low	Increased heating of water	3	2	6
Air Temperature too High	Intensified droplet cooling, increased ventilation, thermal cooling, raising lamps further from the plants	3	3	9
Air Temperature too Low	Increased heating of air	4	2	8
Water Oxygen Level too Low	Increased aeration, increased oxygenation	5	2	10
Pump Blockage	Increased pipe diameter, pre-filtration, overflow drainages, sensor alarm systems	4	2	8
Electricity Blackout	Emergency Power Generators, battery storage	3	1	3
Short Circuit in Electricity System	Good design, good insulation, electricity monitoring systems	5	1	5
Pipe Blockage by Pebbles	Choosing pebble-free cultivation method, pre-filtration, constant monitoring, overflow drainage and piping	3	2	6
Pipe Blockage by Roots	Root trimming, designing plants to have distance from drainage, constant monitoring, overflow drainage and piping	3	3	9
Pipe Blockage by Concentrated Minerals	Annual throughout cleaning, constant monitoring, overflow drainage and piping	3	2	6
Pipe Blockage by Algae	Preventing light from entering the water, constant monitoring, overflow drainage and piping	3	1	3

Water pH too High	Adding phosphoric or nitric acid, increasing temperature	3	4	12
Water pH too Low	Increasing calcium or sodium hydroxide into the water	4	2	8
Market Price Variation of Fish	Extended market contacts, long-term strategy formulation when choosing fish species to be grown	3	3	9
Market Price Variation of Herbs	Extended market contacts, flexible system to change herb species according to market response	2	3	6
Labor Strike	Keeping employees loyal by treating them well	4	1	4
Death of Bacteria Colonies	Stock colonies in storage for quick replanting	5	2	10
Death of Worms in the Bio-filter	Balancing water quality, increased aeration	3	2	6
Sensor Probe Failure	Calibration, cleaning of surfaces, regular comparison measurements with other device	4	3	12
Micro Controller Software Failure	Good design, maintenance contract with the software supplier	3	1	3
Pipe insulation leakage	Good insulation, moisture sensors	3	3	9
Ventilation leakage	Infra-red camera monitoring, air pressure monitoring	2	3	6
Micro Nutrient Deficiency	Plant behaviour monitoring, stock of micronutrients	4	3	12
Insufficient Lighting	Plant growth monitoring, increase in artificial lighting	4	4	16
Fish Feed Supply Distraction	Sufficient constant storage, multiple feed suppliers	4	2	8
Fingerling Supply Distraction	Multiple fingerling suppliers, long-term supply contracts	4	3	12
Wrong Planting Distances	Pruning and bending to control the spread of each plant, transplanting, taking the loss	4	2	8
Blackening Sky	Improved energy security	5	1	5
Automation Malfunction	Sensor system to identify sudden changes within the system	3	2	6

Poisonous Substances in the Water Circulation	Identification of source, slow replacement of water in circulation, chemical countermeasures to negate the effects	5	1	5
Bio-filter Maximum Capacity Reached & Unnoticed	Regular emptying of filtered sludge, purification of cleaning materials, increasing amount or size of bio filters	4	2	8
Too much heavy metals in the water	Identifying the heavy metal source, changing the source of contaminating input	5	2	10
Cannibalistic Fish Behavior	Intensified feeding cycle, increased activities, shading structures	3	3	9
Seedling Trays Run Dry	Gravity-fed watering buffer, moisture sensors, NFT in sprouting	4	4	16
Seedlings Transplanted Too Late	Improved cycle-timing, pruning	4	3	12
Growth Cycles of Plants not Harmonized	Improved design of time intervals of the processes, improved pre-growing system	4	3	12
Phosphate Deficiency	Increasing the level of phosphate-rich fish feed or hydroponic fertilizer	3	2	6
Nitrate Deficiency	Increasing the level of nitrate-rich fish feed or hydroponic fertilizer	2	2	4

TABLE 9. Table of Risks in Aquaponics (Soppela et al 2015)

Appendix 4. List of Aquaponics Facility Components

Land Acquisition	**Foundation**	**Water Distribution**	**Planting unit**
Suitable plot has to be bought or rented with a long-term contract. In lease agreements the Return of Investment (ROI) has to be carefully calculated.	A concrete slab with piping for water, drainage, ground-heat, floor heating, water pools, cabling and under-ground structures has to be casted as the foundation for the facility.	The facility's water input and drainage systems have to be connected to the mu-nicipal water systems or to a separately designed and constructed water intake and water after treatment facilities.	The facility needs to have a separate working space for planting seeds, seedlings and saplings into the har-vested growth trays.
Water treatment Good water quality is es-sential in aquaponics facili-ties, where the water quality affects the wellbeing and growth rates of the involved organisms After treatment of effluent water should al-ready happen within the production process.	**Electricity Transformers, lines and UPS** The facility needs to con-nect to the municipal elec-tricity grid. This might re-quire separate transformers and new connection lines. Capacity should exceed the peak demand during the coldest winter days.	**Greenhouse structures** Polycarbonate and triple-layered glass elements let the natural light in while in-sulating thermal energy. The greenhouse filtration capacity can be replaced during the darkest and cold-est months with RAS bio filtration techniques.	**Fish pools** It is recommended to build the aquaponics fish tanks indoors to more easily con-trol the water temperature. Heating and cooling sys-tems, stimulus environ-ment, flow rate control sys-tems, light sources, aeration and automated feeders are required in each fish pool.
Bio filtering systems The bio filter system is an important and simple envi-ronment to enhance the growth of nitrifying bacte-ria within the aquaponics system. Dead bacteria cells and other solids can be swirl-filtered out of the sys-tem as sludge.	**Water measurement and control systems** DO, pH, amount of ammo-nia and nitrates, air temper-ature, water temperature, relative humidity, and light intensity should be moni-tored and balanced con-stantly. These measure-ments are done with auto-mated sensor systems or by manual laboratory analysis.	**Ventilation systems** Air temperature, air flow rate, relative humidity and CO2 rate control systems are essential in controlling the micro-climate condi-tions within the greenhouse. The circulating water from fish tanks can be purified from CO2 by trickling-ven-tilation.	**Heating and cooling sys-tems** Temperature control is an integrated system consist-ing of electrical heaters, combustion ovens, solar thermal collectors, district heat pipes, heat-pumps, ground heat systems or thermal batteries that trans-fer and storage thermal en-ergy according to the sea-sonal needs.

Lighting Control systems The spectrum and cycling of light has to be separately chosen for the young aquatic animals, mature aquatic animals, terrestrial plants in vegetation phase, terrestrial plants in blooming phase and for people working in offices and processing lines.	**CO2 production systems** Availability of CO2 in the greenhouse can be a limiting factor for plant growth. Levels can be increased by designated technology, releasing CO2 from fish pools, adjusting combustion exhaust in or composting inside. Blow-through ventilation removes CO2 from the greenhouse.	**Solid Waste management systems** Most of the aquaponics facility waste is organic residue and inorganic packaging materials. The organic waste can be composted on site and inorganic waste separated, stored and transported to the nearest material recovery facility. Waste production rate and transport interval define the needed storage.	**Hydroponic growth platforms** Hydroponic platforms are chosen according to the grown species, most efficient workflow, available space, available technologies and synergy benefits with other systems in the design.
Transport lines and equipment Transportation equipment for hydroponic planting trays, fish feed, harvest, packaging material, cleaning equipment, spare parts, construction materials and people are needed within and outside of the facilitie.	**Plant Harvest Treatment unit** The production line will require a separate space for handling the harvest. Planting trays have to be emptied, growth pots to be recycled, unaesthetic leaves to be trimmed and the plants washed. Also staff hygiene needs to be supported.	**Packaging unit** Treated harvest is transported to the packaging unit, where the plants are packaged according to the client requirements. This unit requires a separate storage for the unobstructed availability of packaging materials.	**Pest Control Systems** Pests can be controlled with chemicals, insects, pheromones, increasing host plant resistance, temperature changes and light spectrum changes (Thacker 2002).
Office & Social Space Aquaponics facility, like any other production facility, needs proper office and social spaces for the workers to maintain personal hygiene, arrange meetings and conduct business operations.	**Water Circulation Systems** Water cycling between the fish pools, bio filters, hydroponics, droplet coolers and heat storage has to be accurately controlled.	**Electricity Production Systems** Internal electricity production systems, such as wind mills, photovoltaics and combustion generators can secure operations during the peak demand days and blackouts.	**Sapling and Seedling production** In case saplings and seedlings are not purchased but produced within the facility, separate space with heating and lighting equipment is to be reserved for the purpose.

TABLE 9. Aquaponics design components, page (Soppela 2015).

Appendix 5. Plant disease and pest control chemical consumption (L / 1000 m_2) and cost in Finnish greenhouse production (Based on Parikka 2003).

Common plant disease control methods (L / 1000 m2)

Chemical	**Target**	**Tomato**	**Cucumber**	**Price/kg**	**Total Price To-mato €**	**Total Price Cucumber €**
Previcur N	Pythium		0,46	108,34	**0**	**49,8**
Mycostop	Fusarium	0,04	0,05	8880	**328,56**	**399,6**
Rovral	grey mold	1	0,67	43,62	**43,62**	**29,2**
Sulphur	bloom	0,25	0,33	1,6	**0,4**	**0,5**
	Plant pest control					
Chemical	**Target**	**Tomato**	**Cucumber**	**Price/kg**	**Total Price To-mato €**	**Total Price Cucumber €**
Appalaud	*Aleyrodoidea*	0,18	0,18	1015,14	**182,72**	**182,7**
Torque	*Tetranychus urticae*	0,25	0,33	262,64	**65,66**	**86,7**
Plenum 25 WP	Aphids	0,3	0,4	99,23	**29,76**	**39,7**