Aquaponic systems

Potentials on a northern latitude

David Carlsson
Spring, 2013

Mittuniversitetet
MID SWEDEN UNIVERSITY

MID SWEDEN UNIVERSITY
Department of Ecotechnology and Sustainable Building Engineering
Author: David Carlsson.
Email: david.carlsson@gmail.com
Spring semester, 2013.

Abstract

Aquaponics is a food production method that combines hydroponic and aquaculture to form a system that, through symbiosis, re-circulates all the water and nutrients – and thereby negates any discharge of eutrophied or contaminated residuals – in order to grow terrestrial plants and aquatic life. To study the possibilities of aquaponics at northern latitude, a small scale aquaponic system was constructed in Jämtland, a county in the Mid Sweden region (latitude 63°) and studied while running over a nine month period, August 2012 to April 2013.

The fish species grown in the fish tank was a species of trout prominent in local lake and stream fauna. The plants in the growbed were a mixture of different flora with herbs as a dominating part. Water from a local groundwater well was used. At start, appropriate nitrogen level in the system was achieved by adding ammonia. The values of nitrate, nitrite, pH, carbonate and total hardness were analyzed in repeatedly measured samples. The values stabilized quickly and stayed stable over the duration of the experiment. Heavy metals were analyzed at one point in time and showed no levels causing reason for alarm. Electric energy use for pumps and lighting was measured to reach close to 40 kWh per month.

The trout growth was monitored and found to be comparable with (equal or slightly higher than in) the conventional aquaculture where the fish were originally obtained, when comparing with the same species and same brood. Among flora three herbs were the species thriving best, Oregano, Rosemary and Thyme. They kept growing throughout the winter with Oregano never ceasing to bloom. The total mass of produced vegetables and herbs were fairly low, since the herbs grew best. Results indicate that present aquaculture systems (fish only) could potentially be converted or adjusted into aquaponic systems (recirculating and purifying the water through a growbed) and thereby decrease potential risks of fresh water pollution from fish farming, especially regarding excessive nutrients.

From the results in this study it seems aquaponic systems on northern latitudes are more favorable if focusing on fish growth, with herbs or vegetables as added benefit, and not focusing on maximizing vegetable growth. Continued studies would do well to investigate optimization parameters through, for instance, mass balance calculations and to identify optimal mixtures of plants over the year.

Keywords: Aquaponic, Aquaculture, Growbed, Biodiversity, Trout growth, Fish tank, System analysis, Closed loop

Table of contents

1 Introduction

Aquaponics is a food production method that combines the, now, traditional hydroponic and aquaculture to form a closed-loop system that, through symbiosis, re-circulates all the water and nutrients in order to grow terrestrial plants and aquatic life. To study the possibilities of aquaponics at northern latitude, a small scale aquaponic system was constructed in Jämtland, a county in the Mid Sweden region (latitude 63°) and studied while running over a nine month period, August 2012 to April 2013.

The underlying cause for this experiment adheres to the clear and present fact how humans, on a global scale, are in a constant need of growing crops and feeding our families. Regarding how the ways to do so is constantly being commercialized and streamlined from the traders' point of view to the consumers. Commercial trading in the grand scope, as it is today, is not on a sustainable path. It is sooner on a trail to which there is no gain without a continuous diminishing of natural resources and no way of closing the circle. While the ideas concerning ecological farming, locally produced crops, and so on, are on a slight rise, these ideas are not without problems of their own. As such; opinions from those who look to secure their own cash-flow, flowing through conventional ways of procuring food, act as spanners in the works for any new, improved or else changed approach. As with almost every other tiding of innovative conduct they start off climbing a wall of antagonistic opinions, purposive or not. Nevertheless; through this report I intended to convey an idea concerning an unconventional way of producing food in a small scale and to compare results to the related, currently conventional, way. For this a small scale aquaponic system was constructed.

1.1 Purpose & Goal

As purpose and targeted goal for this thesis laid the research regarding and surrounding the feasibility of whether or not a small-scale homebuilt aquaponic would work on northern latitude.

The target goal will be to ascertain the possibility to, in an energy-effective and cost-effective way, produce vegetables and fish in such volume that it'd be feasible for a family, for a larger complex or for an even larger area, such as a city-wide system, to employ this method. The progressive headway of this study will be aligned in order to show how well the trout grows in the built aquaponic system compared to a conventional aquaculture with the same trout species of the same brood as well as finding out what plants grows best, out of a gathered selection, in this system to supplement the trout growth by purifying the water.

1.2 Method

Overall and in brief; this investigation, this case-study, is based on an experiment on a constructed aquaponic-system and its performance. The experiment is detailed in the report as to allow for further investigation in the same area to either further my results or attempt contradicting them.

The method regards, as the goal states, the challenge to in tandem; construct, measure, examine, recount and lastly propose possible potentials of a year-round food production at home. To compare and assess results with those gathered from studying other systems and theories. And finally combine these studies to contrasts and derive conclusions in order to find the weak points and the strengths for this study at local level with entrained global inspiration.

Thus; this report is based on literature studies regarding aquaponic systems, research and experiments. Results derived from underlying research and the construction of a prototype as well as from running and managing said prototype to carry out tests over a winter season. The coming chapters will move on to describe, in further detail, to how certain parts was constructed, what method of construction was chosen, how some preparations came about and what issues and problems was encountered. The chemical balance will also be looked into and examined. The log kept for the entirety of the project time and all measurements of and results from chemical and physiological analysis, weighting, and information about seeds and plants used which are all available locally. The trout were weighed by resetting a scale when a bucket of water was placed on it. In order to be able to double check the figures the filled bucket was also weighed and the numbers saved for "double counting" the average weight. Once the bucket was in place the trouts were netted and put into the bucket. Once gathered the bucket was weighed and an average weight per trout could be calculated. The parameters measured of the water contain the chemical analysis of the water to see, over time; pH, carbon and total hardness, content of nitrite and nitrate. An inductively coupled plasma mass spectrometer (ICP-MS) was used to measure concentrations of twelve metals. ICP-MS is a variant of mass spectrometry that is able to detect metals and non-metals at very low quantities. The results regarding plants and their growth are based on trials and ocular observations. The results regarding fish growth are based on weighting on a scale. Comparisons were made to fish growth in a conventional aquaculture growing trout, based on the same batch from which specimens for the aquaponic were gathered.

2 Background

2.1 The aquaponic concept

Before going into the details of this work I will begin with explaining what is meant by an Aquaponic so that there will be no misconceptions about this further on as much of this work is based on just that.

Aquaponics is a food production method that combines the, now, traditional hydroponic with aquaculture in a symbiotic relationship that facilitates a sustainable system with little input necessary as all the water and nutrients within are re-circulated in order to grow terrestrial plants and aquatic life. Aquaponics is, in a 2009 article in "World Aquaculture", defined as "The integration of two separate, established farming technologies - recirculating fish farming and hydroponic plant farming." (Wilson Lennard, 2009). Similarly, the Oxford English Dictionary defines Aquaponics as "a system of aquaculture in which the waste produced by farmed fish or other aquatic creatures supplies the nutrients for plants grown hydroponically, which in turn purify the water" (Oxford Dictionaries, 2013). As these preceding definitions shows, the word "Aquaponic" rather clearly denotes a combination of the words "aquaculture" and "hydroponic". The term "Aquaponic" is still a bit prospective and has only just recently, as of September 2012, been brought into the Oxford English Dictionary (Oxford Dictionaries, 2013). Even though it states how the word originated from the 1930's a few years ago it was not searchable here.

The word "Aquaponics" does also appear as an entry on Wikipedia, and did so much earlier than the dictionaries, demonstrating that this concept has moved into the public domain and suggests how interest surrounding it is on a rise. As of March 25, 2013, this open source repository of knowledge online encyclopedia, whose knowledge evolve with time as information is updated by its users, defined Aquaponics as:

"[Aquaponics] *is a sustainable food production system that combines a traditional aquaculture (raising aquatic animals such as snails, fish, crayfish or prawns in tanks) with hydroponics (cultivating plants in water) in a symbiotic environment. In aquaculture, effluents accumulate in the water, increasing toxicity for the fish. This water is led to a hydroponic system where the by-products from the aquaculture are broken down by nitrogen fixing bacteria, then filtered out by the plants as vital nutrients, after which the cleansed water is recirculated back to the animals. As existing* *hydroponic and aquaculture farming techniques form the basis for all aquaponics systems, the size, complexity, and types of foods grown in an aquaponics system can vary as much as any system found in either distinct farming discipline*" (Wikipedia, 2013)

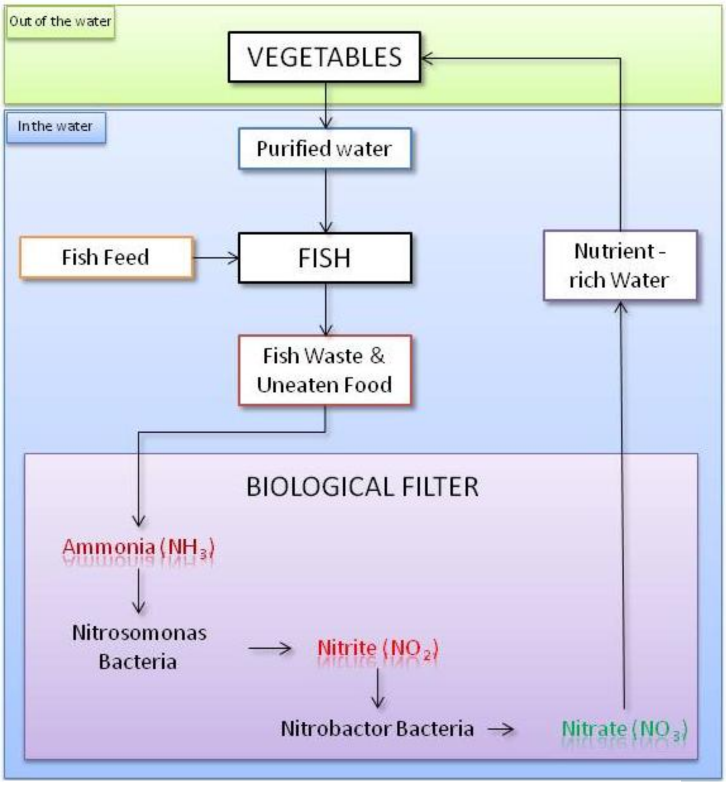

Figure 1 - The Nitrogen Cycle, in an aquaponic. Chart by author.

The traditional reference compendiums provide further understanding about what the definitions *hydroponics* and *aquaculture* can encapsulate if they're combined. The *Oxford Dictionary* defined aquaculture as "the rearing of aquatic animals or the cultivation of aquatic plants for food." (Oxford Dictionaries, 2013) and the *Merriam-Webster Dictionary*'s definition reads "the cultivation of aquatic organisms (as fish or shellfish) especially for food" (Merriam-Webster Dictionary, 2013). About hydroponic the *Oxford Dictionary* says "the process of growing plants in sand, gravel, or liquid, with added nutrients but without soil." (Oxford Dictionaries, 2013) where as the *Merriam-Webster Dictionary* defines it as "the growing of plants in nutrient solutions with or without an inert medium (as soil) to provide mechanical support" (Merriam-Webster Dictionary, 2013) signaling the cardinal difference between it and conventional farming.

Even though plant growth in an aquaponic is visually and systematically vastly different from a conventional growth, in farms and the likes, the same natural requirements is in place. And although the actual science of Aquaponics is still in the early stages of its development, the biochemical cycle within it, cycling within the system, is quite well understood. The most important is *the nitrogen cycle* (figure 1), which in an aquaponic is the key element cycle as it symbiotically provides fertility to plants as well as cleans the water for the fish, removing the toxicity they'd be subject to otherwise. The nitrogen cycle here occurs as the water flow through from fish tanks to biological filters containing bacteria situated on surface areas, to plants or a *growbed* and back again.

The major input into this nitrogen cycle – except for electricity which here is required for the pump to circulate the water – is fish food which is either in the shape of commercial fish feed or aquatic plants, depending on the type of fish and plants in a given situation. After the fish eats the food they produce waste. This fish waste, as well as any uneaten fish food, starts to break down and, from this, the majority of the nitrogen content form ammonia (NH_3). This ammonia is then, thereafter as it flows through the biological filter where Nitrosomonas bacteria is situated, converted to nitrite (NO_2) after which a second type of bacteria, Nitrobactor, converts nitrite into nitrate (NO_3) (Manahan, 2010). It is this nitrate that then, as it flows through the growbed, serves as a fertilizer for the plants therein. As such the plants, in this hydroponic component of the system, take up the nitrate - that helps them grow - by removing it from the water and as such purifies it as it circulates back to the fish tank returning clean, fresh water for the fish to thrive in.

An aquaponic system can work with several types of aquatic animals being grown. In my scenario the animal in question is a local family of brown trout (Salmo trutta morpha lacustris). The trout is a rather tolerant species with an inherent resilience allowing it to survive a certain shift in pH range and it thrives in temperatures between 4 and 20 degrees centigrade, peaking at 10-15. It is, however, susceptible to harm should the water become too warm, effectively making trout a less viable option for warmer latitudes. It also requires a high level of water oxygen content, so an aquaponic system must be constructed taking this issue into consideration (see 3.1.3). In general almost any freshwater fish and shellfish can be cultivated using aquaponics. Similarly, a wide range of plants can be grown in this kind of system. It is, however, easier to grow plants that do not have large roots that might cause them to rot, depending on what system-flow you utilize. More information about varieties of this will follow in section 3.1.4. Plants within a low to medium nutrient requirement tend to do best. We'll later go through how a variety of herbs seemed to grow best in my example where I tested a variety of different plants, and not just vegetables for food production, simply to observe potential differences in growth affinity and adaptation.

Today we can read and hear about an increase in the popularity of these systems (Rakocy, 2010). More and more organizations are considering a potential use of aquaponics in terms of its vast array of benefits including a reduction of aquacultural runoff, reduction of the need for irrigation in crop-growth, a non ocean-depleting source of fish-stock, the potential to grow food on areas of poor soil quality as well as on polluted land. There's also an interest growing from the educational sector as aquaponics displays a variety of teachings in "ecological literacy" within an easily graspable, viewable and functional system. There are also ideas how aquaponics can operate as a certain community-hub, creating activity, training and job-opportunities. However, despite all these benefits there was no real documentation or conclusion found regarding whether or not aquaponics is a profitable venture in this region (Mid Sweden region, Jämtland County, latitude 63°). Therefore this turned an interesting topic to research.

2.2 Previous research

Research in terms of aquaponic systems from this latitude is sparse. A deviation to such a statement is shown in an example of how some studies regarding aquaponics have taken place on this latitude prior. But instead of focusing on a systematic improvement these have focused on education. One example is the European collaborative project "Play with water" which Mid Sweden University took part in for their teacher education (Play with Water, 2007). The objective of that project was to describe the systems and how the work with them had proceeded, to evaluate possibilities to use the system in education and then to evaluate the general pupil understanding of it. While I'm sure this was a good project it didn't really fall in line with my aim.

Another example is "*Kattastrands kretsloppsodling*" in Härnösand, Sweden. They've been building and attempting aquaculture and aquaponic ideas, in rather small scale although larger than my example, for the last 15 years. This is a European Union-project with a goal to develop and demonstrate the possibility to use aquaculture together with plants in places where there is a lack of water and not aimed at optimizing growth in the system (Kattastrands kretsloppsodling, 2012). Their system, at times, operated in higher temperatures than mine did and they did not cultivate the same species of local fish but rather koi or goldfish. In total their amount of produced vegetable reportedly weighs 10 to 20 times their amount of produced fish. There was, however, hard to draw conclusions in terms of economic growth and systematic improvements from this project.

This brings me to draw inspiration from research in other areas. From 2004 we can find a quite notable, and descriptive, publication by Dr. Rakocy about the financial angles of aquaponics (Rakocy, 2004). In this study he compares the levels of productivity and gross income of basil and okra first grown in conventional fields versus those grown in an aquaponic-system. Rakocy’s study shows a sturdy 18 (basil) and 3 (okra) times higher productivity respectively, in an aquaponic compared to the regular field. The study took place in the Virgin Islands where the gross income levels from basil and okra, based on the current market prices there, came in at a projected $515 worth of vegetable grown per cubic meter, per year, in the aquaponic-system versus a $172 worth of vegetable grown per cubic meter, per year, for the conventional system. To highlight; a cubic meter of a growing-area within an aquaponic-system yielded more vegetables, more harvest, and therefore reached a higher figure. Then, when adding in fish sales, in their case consisting of tilapia, the system had a projected gross $132,245 versus $36,808 per year on the same growing area. That is; the same size area of growth was compared with one being a regular area of cultivation and the other being an aquaponic growbed, the latter being able to add the fishes tied to the system, present in a nearby fish tank, into the calculation. This might give aquaponic production an initial appearance as the economically superior choice between it and conventional field productions, but as has often been the case for discussions and what seem to be an oft reoccurring issue is that this study does not, like several others, take into account costs of production. Neither does it conduct a cash flow analysis in order to determine any estimated net income, which would be a crucial calculation to any investor, farmer, complex or business owner who might consider an aquaponic installation. This, as with most of Rakocy's research, based on numbers from an outdoor tropical growing system No outdoor field or aquaponic system would work all year round in Mid Sweden’s cold climate. Thus, the results from Rakocy's work are not directly applicable to aquaponic systems in where this experiment took place.

To make a greater effort into seeing how financial aspects could tie into the ideas of aquaponics we also have to look further into the fact that an aquaponic can be constructed in a multitude of ways and volumes. Given that fact one can easily realize that a potential financial outcome would differ depending on the form and variant of an aquaponic at a given location. So, to clarify how the importance of such differences can become something of a sudden paramount we look at some old findings showing how it, already at a construction level, becomes important to align an aquaponic depending on the wished outcome. The component ratio, the ratio of solid media for growing to water, can be altered to align and optimize for fish production or plant production depending on a constituents wish and plan (McMurty *et al*. 1988 and McMurty *et al*. 1990). As such there can be a maximization reached, in terms of profitability, here as well as in a maximization of production through the component ratio. This alone does not guarantee an economic offshoot, it is simply provided to show how there is in a venture such as this, just like any other, a plurality of different divisions to take into account. However, it stands to show that by employing an aquaponic system thinking there opens up new areas and thus new potentials for combined and increased cash flow.

3 Practical investigation

To find out whether a small scale aquaponic, on a northern Scandinavian latitude would function according to theories and perhaps more importantly would work and give a positive result at a northern latitude where I live I could have read to days' end. Instead I decided that I would design and construct my own aquaponic. There I would be able to, from first hand, measure and observe its progress and functions. During the summer of 2012 I commenced and subsequently finished its construction, after which the system was running from late summer 2012 and throughout the writing of this report in spring 2013. More details about this construction will be covered in the next chapters.

The construction was based to operate on spare heat. Evidently it was not built outside as temperatures here in northern Scandinavia drop beneath freezing for a good portion of the year. The aquaponic was constructed in a workshop area, free from chemical and combustion exhaust, which kept between 9-16 degrees centigrade during winter. As such, not a completely stable temperature, with eight degrees variation, but this was an intended design to test the system with an estimated median for a mimicked natural variation in summer temperature.

3.1 Building the prototype

The aquaponic building materials was mainly consisting of reused equipment, the largest of which was the two International Bulk Containers (IBC's). They had previously been used by a printing office and had contained some kind of ink additive. This was many years ago. I judged that they could be cleaned out enough to support life. After physically cleaning the IBC's out I filled them up with water, leave the lids off, and leave the tanks in the sun. This was simply to discover if any algae-growth could take place inside the tanks, and so ensure their capability to support life. After only a few days, algae-growth was detected. Before the construction I had researched different ways of construction and found (Rakocy *et al*. 2006) out that a "flood & drain", also called an "ebb & flow", system would be my system of choice, as opposed to a "continuous flow" (see further section 3.1.4). I was, however, not sure this was the best way of going about, so I ensured my system could, with small adjustments, be arranged to work as a "continuous flow" system as well. "Flood & drain" seem to be the most widely used method of delivering water and nutrients to plants and so to filter the water upon its return to the fish tank. There is a vast multitude of ways one could construct a "flood & drain" system. The main construction was finished after six days, upon which the system was started and its circulation ensured to function as intended. The system was formed to include the following:

- A fish tank with room for 500 liters of water. Constructed from an IBC.
- A grow bed situated above the fish tank, to enable water to flow back without the use of a second pump and to keep the levels of light in the fish tank down. Constructed from an IBC.
- The light metal cage of the IBC's cut and constructed to act as a frame for both the fish tank and the growbed, so that the weight of the water would not bend plastic or put unnecessary strain on its, now, cut edges.
- A water pump, situated 10 cm above the bottom in the fish tank. With a built in float switch.
- A Growspot, a LED light for plants (see 3.1.2), and a timer to regulate it.
- Hosing and cordage to and from the pump and cordage to the Growspot.
- A plastic pipe, molded for use in a culvert, used to preclude fish getting too close to the pump.
- Aluminum net attached to the pipe's top and bottom for the same reason, to keep fish out. Also later added to cover the top of the fish tank.
- Rocks from two lakes in northern Jämtland to support the tank with a better surface for bacterial biofilm to develop and to give the fish hiding places etc.
- Clay beads filled the grow bed, to act as solid media for plants.

- Pipes to transport water, otherwise used for fresh water systems.
- Flotation device to trigger micro switch built first from cork then replaced with Styrolite-foam, and a small piece of treated steel.
- Ball valve to limit the grow bed water outflow.
- The electrical system, situated on the wall beside the tanks, including timer, transformer (from 220 V down to 24 V ensuring a safer working area in the grow bed), two junction boxes, trigger and outlet. Cordage to and from the micro switch situated center growbed.

3.1.1 The design

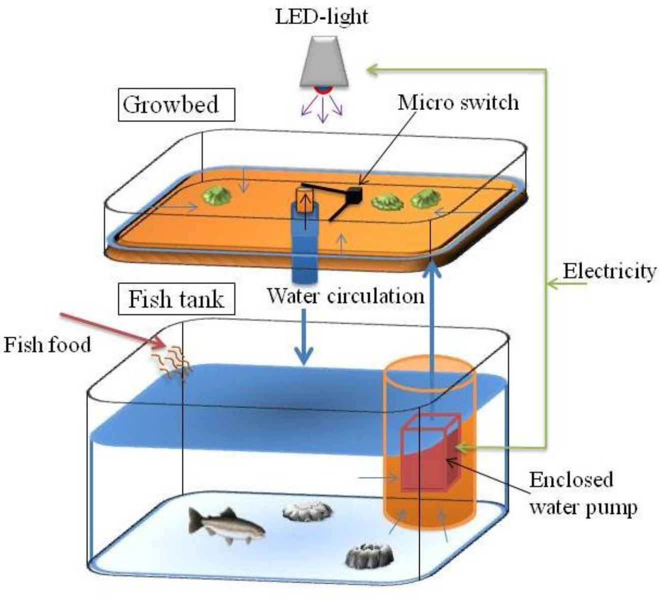

Figure 2 - The constructed system. Figure by author.

Figure 3 - The constructed system. Photo by author.

To touch upon how the system was built to function in this rather closed loop and how the circulation of the nitrogen cycle was attained we can look at a simplified concept of the system shown in figure 2 and a photo of the same, for reasons of clarification, in figure 3. It displays how the water is circulated from the fish tank, where ammonia is excreted from the fish waste and the bacterial cultures, mostly present on solid surfaces such as on rocks on the bottom, convert it to nitrite and on to nitrate.

Water is pumped up to the growbed where it flows out from small holes, every 10 centimeters, on a pipe circling around the entire growbed interior. The pump fills the growbed up with water until the micro switch in the center is triggered from the rising water level, which takes about two minutes, causing the pump to shut down and to start over again after 15 minutes. This give the grow bed around 11 minutes where it is not filled with water as it takes about four minutes for the majority of the water to run back down to the fish tank, controlled with a ball valve at the growbed outlet. From the center of the growbed the water flows back to the fish tank by simple gravity, removing any need for a secondary pump. Clearly, the rate of water entering the growbed when the pump is working exceeds the rate of water leaving, to enable the water level to rise and to reach the plant roots. The design of water entering from the sides and exiting in the center is to make sure the water circulation, too, passed the plant roots so they would never be subject to stale water.

If the micro switch trigger is not released, the 15 minute timer does not start. This provides the growbed with a certain flood protection as the pump can’t start. Therefore more water cannot be pumped in if the level is already too high. As long as the micro switch works, this proved to be a very efficient flood protection. Less so, of course, when the switch got stuck, but more on this issue later (see 3.2.3).

The fish tank is home to the trout, which are daily fed with the same kind of fish feed used by an aquaculture, growing the same kind of trout, in this region. In here is also located the water pump. This device is enclosed in a piece of plastic piping with a net, closing the top and bottom, and small holes drilled in its side. This to make it impossible for the fish to enter the pump but to make sure the water will pass without problem.

The growbed is fairly filled with a variety of plants and during the winter these plants have either remained healthy or been replaced with something else after having wilted or died for other reasons (see 3.3.2). This provided us with additional information regarding this growbed-biodiversity.

3.1.2 Lighting details

The light source is a 15w red/blue LED, “*Super Growspot*”, Fanless, E27 plinth, with an illumination surface of 0.3 to 2 square meters which is enough for this 125cm * 85cm growbed. The effect of this lamp is equivalent to a 190W conventional light bulb. The diodes within are red and blue in a ratio of 11:4 red/blue. This cause the area to be illuminated in, to our eyes, a purple light. The short reason why there are no green diodes, to complete the RGB-spectrum, is simply because plants would gain little from such as chlorophyll, the bio-molecule allowing plants to absorb energy from light, absorbs light most efficiently in the blue portion of the electromagnetic spectrum where it is then followed by the red portion. The reported life span of this lamp is 30 000 hours which, at 16 hours per day, would translate to 5,13 years. The lamp body and heat sinks are made out of aluminum. This removes the need for fans and the need for moving parts, increasing its lifespan. The temperature of the lamp, when lit, stays between 35-40 degrees centigrade which do not burn the plants.

3.1.3 Pump details

The system contains a submersible pump capable of pumping 200 liters of water per minute. It’s hanging 10 cm above the bottom of the fish tank inside the protective pipe. The flow is guaranteed constant through the utilization of vortex technology. In fluid dynamics, vortices are a major component of turbulent flow. A vortex is an area of a fluid possessing a torrent, often a swirling motion, around an imaginary axis, either straight or curved. This movement pattern is known as a vortex flow (Kida, 2001). It’s built with polyamide impellers and corrosion free components to ensure, firstly, its longevity and, secondly, that no toxic and alien substances are leached to the circulating water. The power usage is at 400W. The electrical cordage to the pump is completely separated from the growbed through the constructed connections to allow for a lower voltage in that area, where a physical influence is more common and therefore would run a higher risk of injury were the labor conducted with lacking caution. The pump is also equipped with a floating switch that renders the pump unable to work if the water level in the fish tank for whatever reason would have depleted too much. This means that the water level in the fish tank can’t go beneath the half mark, not counting evaporation.

The pump also took care of the oxygenation of the water. As it was already clearly stronger than necessary, and therefore had energy left over, the system was built in a way that by diverting part of the water volume pumped to fill the growbed instead passed through a nozzle underneath it. The water was sprayed on the water surface in the fish tank and so mixed it with oxygen from the air. This, together with the flow back from the grow bed, proved to give the fish a sufficient oxygen level not to hinder fish growth.

It is important to note that this pump was not optimized for this system, it was however ensured not to be lacking in capacity.

3.1.4 Some considerations during building of the prototype

First, to briefly capture upon two systems “flood & drain” and “continuous flow” and show why “flood & drain” was chosen, follows a description of the two.

A “continuous flow” system dispense the water to the grow bed without stop and the water is oft distributed over the grow bed by some sort of distribution grid. A grid much like the one I made and put in place for my system. A grid consisting of a pipe work with small holes drilled at level intervals to ease an even distribution of water. The water would then trickle down and across the grow media and out of the bottom of the bed. In my system the outlet was in the center of the growbed bottom, forcing the water to run from the edges to the center. A grid distribution system like this is important in ensuring all parts of the bed receive water. Were a grid irrigation system not employed, dry areas would develop resulting in poor and irregular plant growth. It could also create areas with stagnant, anaerobic, water again resulting in poor plant growth.

A system with only a float switch would be constructed so that a pump in the fish tank push the water to the grow bed until it was flooded. The pump could then be shut off by the use of a float switch in the fish tank when the water there reached a previously measured level where enough water had been delivered. The switch being coupled in a way as to cut the power to the pump at that precise level. Or have a switch trigger when enough water has been pumped into the growbed and then stops the pump. My system made use of both methods, while mainly the latter leaving the former as a safety backup, it was created from a mixture of using a float switch and a timer.

Making use of a timer to regulate the flow of water to the grow bed could be considered a safer method than to only use a float switch. I considered, however, that a float switch would still be a useful device installed in the fish tank and set in such a manner as to act as a safety device to prevent the total emptying of it. The float switch built into the pump I used was left intact and thereby adding another layer of security so that the fish tank would not be drained. The design was, however, mainly based on the micro switch in the grow bed to regulate the “flood & drain”.

The flow of water is not unrelated to the choice of solid media, which on its own is important (Lennard, 2012). I concluded that clay pebbles, or clay beads, seemed to be a good medium of choice as they retain moisture and thereby aids the growth of the plants. Clay pebbles have a slight moving effect, through the flowing water input of motion, helping to distribute water to the entire bed.

The need for a second pump to push the water back from the growbed to the fish tank is alleviated in this case, by use of gravity, as the growbed is positioned higher up. Therefore only one pump is required to manage the water-cycle and it is combined with a timer to regulate it. The timer was set to a 15 minute period, enough to deliver the nutrient rich water to the grow bed and to have it drained back to the fish tank ensuring the plants won't get waterlogged. After the time has passed the cycle repeats.

3.2 Running the prototype

3.2.1 Fishless cycling - Growing the bacterial cultures

For an aquaponic to function there needs to be a source of ammonia, as explained in 2.1. In this system I decided to start with what is referred to as "*Fishless cycling*" (Landis, 2010) before adding the trout. When the system contained its intended bacterial cultures the trout would be the source of ammonia as their waste were to be the fuel feeding the aquaponic system. During their respiratory process fish excrete ammonia through their gills. If left unrestrained this would at the end poison the fish. Thus we display the need for plants. The Fishless cycling- alternative simply means that instead of having fish excrete ammonia, I'd add it manually. There are a few major advantages for this execution.

Firstly, as Landis mentions, we experience less stress for both the farmer and the fish as there's no need to keep any fish alive in this process. This makes any sudden jumps in pH, or some such, virtually obtuse.

Secondly one can raise the ammonia concentration to a great deal higher than otherwise would be safe for the fish. This gives the system a shorter time needed to cycle the system and end up with strong and present bacterial cultures. Having the system come into balance sooner also gives us a benefit of being able to completely stock the fish tank all at once, instead of having to stock it by stages. As trout is a carnivorous species new arrivals would be at risk of attack from the ones previously introduced (Raleigh *et al*. 1986). As such, there's a lower risk of the fish attacking each other when they are introduced simultaneously after a fishless cycling-start, when the bacterial balance have already been met, than the risk that would follow adding the fish in smaller numbers and over time.

Lastly, by doing this it's much easier to control the exact amount of ammonia added to the system in its initial process. This gives the opportunity to increase or decrease the amount of ammonia needed for the forming of bacteria.

I started with adding quite a lot of ammonia – a solution of 24.5% ammonia and the rest water – when the first addition was added the 2nd of August 2012, probably more than was needed but this was remediated in time by exchanging the water through an outlet in the bottom of the fish tank while not losing the bacterial cultures since the majority of these are attached to biofilm on solid surfaces. Soon the system was in the sought for balance. Figure 6 shows the rise and fall of nitrite and nitrate, the rise taking place due to the ammonia is being converted, implying how the bacterial cultures are in place. After the water change (see section 3.3.3) the nitrite remained close to zero and with the nitrate rising back upwards again the water was deemed suitable enough for trout to be added. Before that, though, I had time to make sure the electrical solutions, the physical builds and so on held up to what was intended.

3.2.2 Electrical extensions

With some advice from professionals I acquired equipment and received assistance in constructing the electrical system. This included the timers (one for the lamp and one for the micro switch), the trigger, the isolation transformer securing the growbed and area of working by lowering the voltage present and suitable solutions for the cordage etc. The end-result placed the majority of the physical electric system on the wall, next to the aquaponic. On this plate is received power from the grid (220V), after passing through the instruments there is power sent to the pump (220V) and to the micro switch on the growbed (24V) (See Figure 4). The only electrical part besides this plate of joined electrical solutions is the timer for the growbed light. The LED's cord was, combined with a timer, placed directly into the grid (220V).

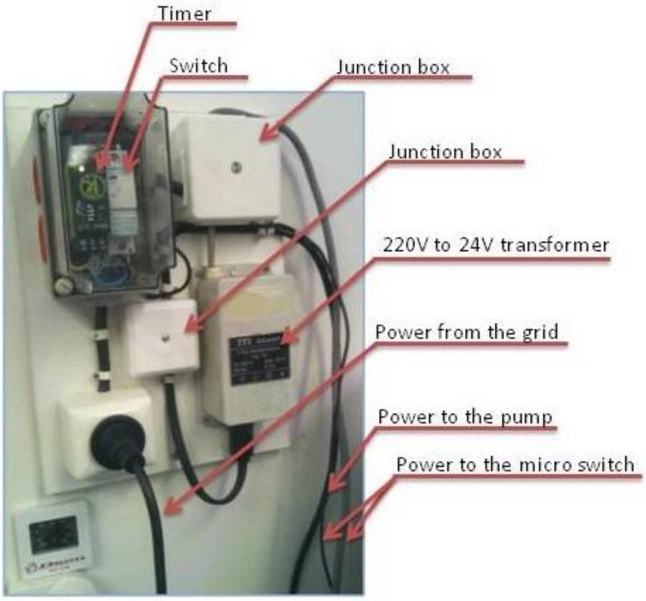

Figure 4 - Electrical system. Photo by author.

The flood and drain-system was ensured to work by constructing a micro switch in the grow-beds centre close to where the water poured back down to the fish tank. The pump would start and pump water until the desired level was reached, and then shut off and the timer would be triggered. That is, the switch would do two things. It first switched the pump of, and the water started to pour back to the fish tank. Then it initiated a timer that made it so the pump could not start again until at least 15 minutes had passed. Had, for whatever reason, the growbed not emptied by then, due to whatever malfunction, clogging, or mishap, the pump would not start seeing how the micro switch would not allowed it had it not sunken down with the water level as it poured back to the fish tank. This was to ensure an avoidance of flooding the growbed. This worked perfectly in theory, but took some adjustments before it kept working in practice too as the system experienced floods, three times, which caused me first to replace the floatation device but eventually to add a reserve-outlet for the water.

3.2.3 Flooding

In total, during the first months, the growbed flooded three times. These occurrences adhered to problems with the floatation device in place to trigger the micro switch to turn the pump off. After the first and second flood, which both washed away some seeds planted there on trial, further optimization for this floatation device was worked on. After the third flood a filtered reserve-outlet was added to ensure the top centimeters would not get flooded. Besides that, here the floatation device was also reworked and refitted with styrolite foam. Previously it had been made out of cork, but it seemed this lacked the necessary buoyancy.

After the reserve-outlet was added there were no more floods witnessed. Or, possibly, the outlet works and counters any flood happening until the micro switch skips back into position.

3.2.4 Adding trout to the system

During mid-October, 2012, I found my system in balance and ready for the introduction of fish. Having previously contacted "*Bonäshamn Aquaculture*" situated close to Järpen in Åre municipality I had been informed, by their site manager Bertil Sellsve (Bonäshamn Aquaculture, 2012), that they were inclined to assist in my research as well as provided some practical information. On October 18, 2012, I picked up the trout for my experiment and noted down the data needed, date of brood and some identifying numbers and figures, to make sure future figures could be compared to the same brood still at the aquaculture. The fish was added as soon as the temperature in the water the fish was transported in had reached the same as in my fish tank to avert any sudden shock potentially harming the specimens. Every fish survived the ordeal, so from October 18 all ammonia was added by the trout.

3.2.5 Feeding the trout

From the beginning the trout were fed with 4 grams per day (a figure suggested by an employee at the aquaculture) of Aller Performa (Aller Aqua, 2012), the same type of feed given to the fish at the aquaculture. This was increased to twice the amount, 8 grams, by the end of April. This is likely an area that could have been more perfected, but distance to the system, available time and means resulted in a rather linear method of feeding. It was checked, however, that no detectable amounts of feed was left over in the tank in which case the feeding would have been lowered. It was increased to 8 grams twice, once in January and once in Mars, but subsequently reduced back to 4 again after traces of left over feed was detected.

3.2.6 The growbed: A closer look at the plants

The reasons behind how I selected plants to run in this project were partly out of personal preference, I tried to grow plants I find myself to subjectively like, and partly out of what tend to be available in this region and so perhaps run a greater chance of surviving a slightly harsher climate than a warm summer or a green house.

By the mid June I planted several seeds, mostly herbs and different chili-fruits, in grow pots and put them in a greenhouse. Apart from these species several others were eventually planted into the growbed but they were started, sprouted, elsewhere. Once the system was in order and the plants were large enough they were added to the growbed. Not everything was added at once, but as room was created due to some plant withering it was filled by something else. Some of the tested plants are known annual crops and were not likely to survive winter, or a “continued summer”, but as there are still many unknowns in the area the growbed was used to observe this occurrences in practice.

The precise selection of the plants test in the growbed is shown in table 1 in chapter 3.3.2 where further information about the results can be found.

3.2.7 The five master building-blocks for plant-growth

As mentioned in 2.1, despite the technological difference between an aquaponic and conventional growth, the same natural requirements remain. For plants to grow they require energy educed from solar radiation and various elements like carbon, including carbon dioxide, sulfur and nitrogen received here from surrounding air and atmosphere. The final three building-blocks enabling growth include a medium for physical support, water and mineral nutrients. (Rydén, 2003). These nutrients compose, in tandem, chemical building blocks for how plant life is raised and structured. This last building block, the mineral nutrients, was the only question of a real difference compared to soil as a medium. But seeing how it seemed to have worked in other examples (Lennard, 2012), and clay basically being made out of soil, it seemed viable. Micronutrients are primarily derived from organic decomposition, ion exchange reactions and mineral weathering. They include copper, carbon monoxide, iron, zinc, manganese, boron and molybdenum. The macronutrients are generally and recurrent traced as components of carbohydrates, proteins, chlorophyll, nucleic acids and lipids and include phosphorous, potassium, calcium, magnesium and sulfur (Manahan, 2010).

In nature these last three blocks are by and large connected to the soil and it is therefore shown that a high quality soil is paramount (Rydén, 2003). Here remained the question, then, were my clay beads up to the task of proving the system with its needed resources? It was a quick thing to check of water and a required physical upkeep as this was clearly visible and known from the start. The mineral nutrients, however, are harder to detect. To see if these old clay beads would do the soil’s work there was naught to do but to test it.

3.3 Results

Here follows a detailed look on fish growth, plant growth, chemical measurements and energy use over nine months of running the aquaponic prototype constructed in this project, August 2012 to April 2013.

3.3.1 The trout growth

One of the more interesting things in this venture was to find out whether the trouts in the aquaponic had kept up with the rest of their batch still in the aquaculture in size and weight. When I received the trouts on October 18, 2012, they had been weighed, at the aquaculture, a few weeks earlier. At that point the average weight of each fish was 2.5 grams and measured around 5 cm in length and less than one cm across the abdomen. These figures, weight and length, were given to me by the site manager at Bonäshamn Aquaculture (Bonäshamn, 2013), but of course a rough length of 5 cm on average could be observed by the naked eye.

In order to compare the progress of my aquaponic system with that of a conventional aquaculture with the same specimen I arranged for my group of trouts to be weighed at the same time as trouts from the same batch still at the aquaculture. After the winter had passed, on April 25 2013 when the fish had been in the aquaponic a little more than six months, I weighted the trouts in my fish tank and calculated their average weight per fish. The aquaculture personnel did the same, for the same batch during the same day. The only difference in method was the amount of fishes used to derive an average weight. The aquaculture, with their larger broods, gathered 50 fishes (Bonäshamn, 2013) whereas I gathered and weighted 20 fishes, of the at the time total of 22, present in the aquaponic. Both Bonäshamn and I did visually detect a similarity in size between the fishes weighed in our separate undertakings.

The results were as follows:

- Aquaponic: 20 trouts weighed giving an average weight of 4.80 grams per fish.
- Aquaculture: 50 trouts weighed giving an average weight of 4.54 grams per fish.

This shows a difference of +0.26 grams for the aquaponic trout, a 5.4% higher value.

The trouts seemed to thrive and gain strength. During mid-May 2013, one trout - measuring between 17 and 18 cm in length and about 4 cm across the abdomen - managed to jump out of the fish tank. The water surface in the fish tank is at least 20 cm below the top, less when the water is being pumped, and the inside of the tank is curved inwards.

3.3.2 The plants growth

In table 1 all species tried in the growbed are listed, with a brief account on each. Those above the gray line represent species that were grown for this project alone, from seed to sapling in a greenhouse or similar, and those below the gray line represent the species gather elsewhere from e.g. a home garden or a plant shop. A simple connection is noticed between "*Degree of thriving*" and whether or not the plant was aggravated by aphids and while this might be sometimes the primary reason it is not necessarily the only reason.

Figure 5 shows how the growbed looked on April 11th, 2013. Closest to the camera, from the left, one can see the chives, strawberry leaves, thyme, oregano and the bigger orchid-leaves. Beyond the white pipe, containing the electric cordage to the micro switch, we see basil, rosemary and the Northfolk island pine.

Results showed that in the climate of this system the Capsicum species did not thrive, while the various herbs, with the exception of Basil which struggled to remain brisk, on the other hand did. The oregano especially so, it kept blooming and growing through the entire winter. The herbs, with the exception of the Basil, did not suffer from the aphid infestation either, proving they held another advantage.

The dill was lost after one of the floods, likely the plants were not large enough to have taken root yet. The chives started out well, but come early fall they withered down and remained so until late February when sprouts were again detected. By mid-April they had grown 10-15cm.

In my experiment I've witnessed, studied and tried to remediate a tenacious aphid infection. For more information see the Aphids factsheet (University of Rhode Island. 1999). This was the major issue and problem in this project surrounding and concerning the growbed. It is likely that they entered the growbed by following one of the species which was moved there from outside. The aphids proved a relentless aggravator for many of the species, resulting in their death or "*growth-halt*" while other species remained untouched by them. I tried to remove the aphids by using my hands and by spraying them with soap water, not wanting to introduce any too alien chemicals that could upset the balance or harm the fish. I did not manage to remove all of them but it seemed, through keeping a close eye on the different leaves, I kept their numbers down. The pelargonium was the only species that seemed to survive rather well even though assailed by aphids. Granted the species have rather big leaves making it easy to remove them by hand, as I did, but it still kept growing and seemed to thrive rather well.

Table 1 - Species in the growbed results.

Name	Species family	Degree of thriving	Notes	Aggravated by aphids?
Habanero	Capsicum Chinense	Bad	Grew well for the first months, then stopped perhaps due to aphids	Yes
Jalapeño	Capsicum Annuum	Bad	Grew slow, then stopped. Perhaps due to aphids	Yes
Bell pepper	Capsicum Annuum	Bad	Same as the Jalapeño	Yes
Basil	Ocimum basilicum	Average	Stayed healthy for ~2 weeks, then suddenly withered.	Yes
Oregano	Origanum vulgare	Good	Kept flowering through the entire winter	No
Rosemary	Rosmarinus officinalis	Good	Grew well over winter	No
Thyme	Thymus vulgaris	Good	Grew well over winter	No
Parsley	Petroselinum crispum	Average	Stayed healthy but did not grow much over winter	No
Leaf Parsley	P. crispum Foliosum	Bad	Withered after a few weeks	Unknown
Rucola	Eruca sativa	Average	Grew unevenly	Unknown
Lettuce, Iceberg, Leaf, Romaine	Lactuca sativa	Average	Grew well until the aphid infestation overcame them	Yes
Dill	Anethum graveolens	Average	Lost in flooding	Unknown
Chives	Allium schoenoprasum	Good	“Overwintered”, started to grow again in late February	No
Strawberries	Fragaria × ananassa	Average	Grew 2 months, then slowed	Yes
Orchid	Orchidaceae Phalaenopsis	Good	Seemed to survive well	No
Pelargonium	Pelargonium hortorum	Good	Settled well. Flowered thrice	Yes
Norfolk Island Pine	Araucaria heterophylla	Good	Kept growing and looking healthy	No

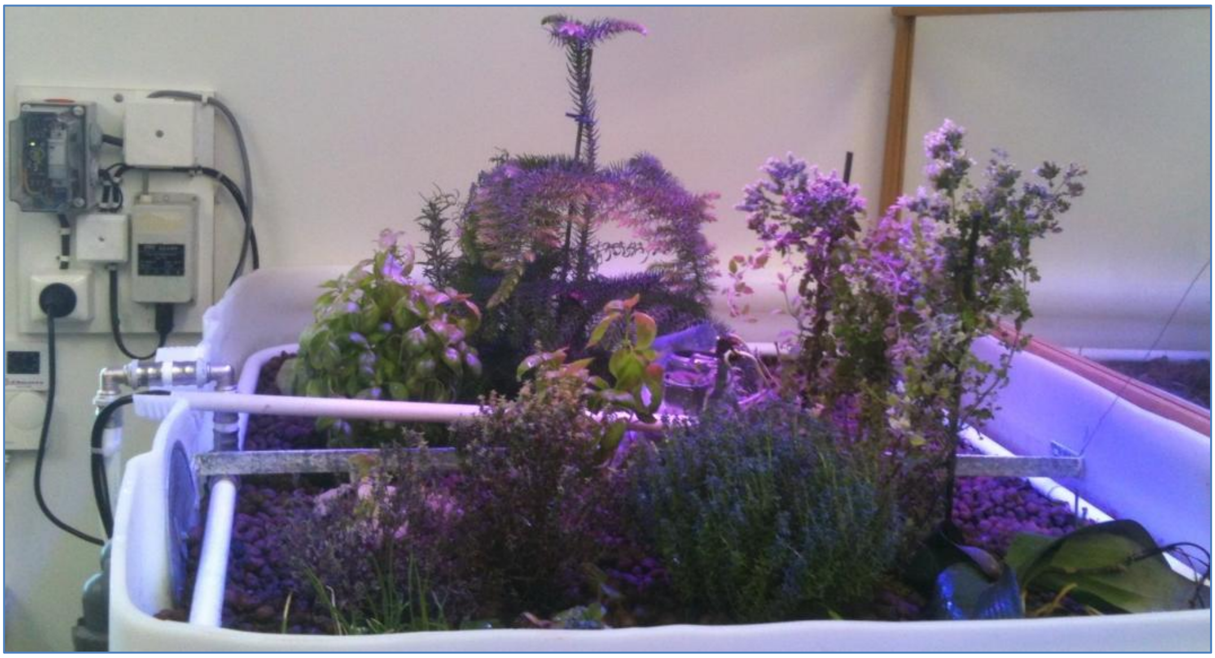

Figure 5 - The growbed as of 2013-04-11. Photo by author.

3.3.3 The water quality

Figure 6 is showing the value of nitrite and nitrate over time. The early, very fast rising values was due to the added amounts of ammonia into the circulating water and as the bacteria grew exponentially so did the nitrite and nitrate values. It’s clear to see how after the water exchange (see section 3.2.1), the nitrite values had reached zero, indicating a virtually total conversion of remaining nitrogen containing species into nitrate and remained steady thereafter. Nitrate changed a bit over time. The rise in concentration that can be seen in February, I credit to a combination of having some plants dying combined with fish growth. That is; more nitrates to go around but fewer plants to bind it, purify it. The early high spike – between September and October - in both nitrite and nitrate was estimated since the instruments used did not show a precise value above 500 mg/l. My theory is that the added high amount of initial ammonia facilitated growth of the bacterial cultures in a briefer time than if the system would have started with fish, as ammonia producer, from day one.

Together with nitrite nitrate I measured pH; the results are shown in figure 7. This was not a cardinal value to observe during the first months of fishless cycling, but just before and when the fish arrived this was suddenly a very important value to keep in check as an excessive spike or drop in pH is hazardous for species like the trout. As can be seen the early pH-measurements were the highest, after the addition of the initial ammonia, which was to be expected as the ammonia solution added was an aqueous solution with an ammonia concentration of 24,5% and thus only moderately basic, and before any bacterial cultures had had any time to grow. Then it dropped during the first month and remained quite steady. No problems were observed from a sudden pH fluctuation. I also measured the initial pH of the incoming water directly. This was showed to have a pH of 6.9. Added here for reasons of clarity and to elucidate further, only to show the initial value and to give an idea where the pH starts in water being added to the fish tank.

Apart from these values I also measured the total hardness and carbonate hardness of the water, figure 8, even though I do not believe these values hold a significant position in this endeavor. What is, perhaps, interesting to note is that the hardness of the water followed the pH and the nitrite and nitrate-curves very well. That is; from October 2012 when the fish was introduced the curves’ remain rather balanced.

To elucidate: Each time the values were measured, for the charts below, all the values were taken at the same time. Therefore the markers on the curves vertically coincide.

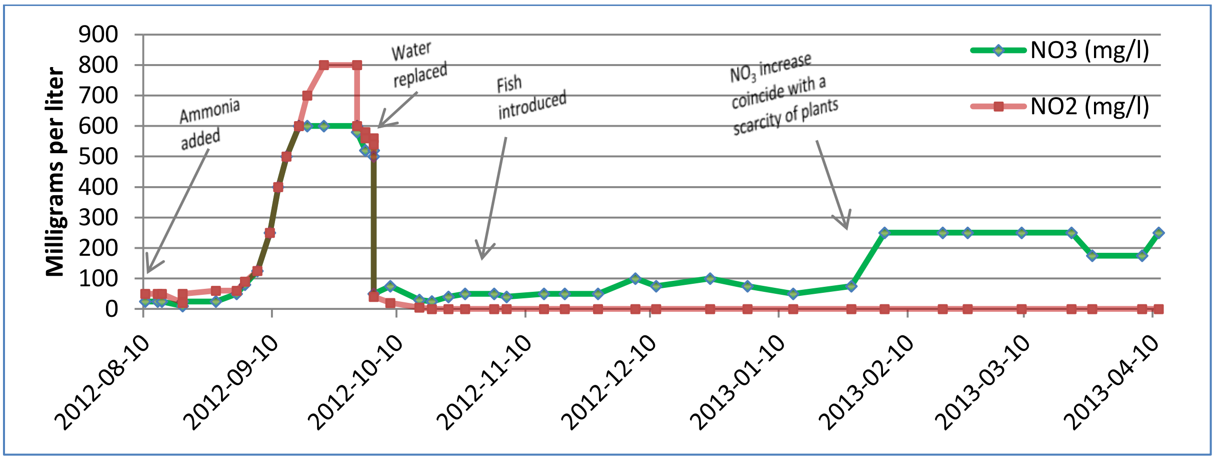

Figure 6 - Fish tank nitrite and nitrate values.

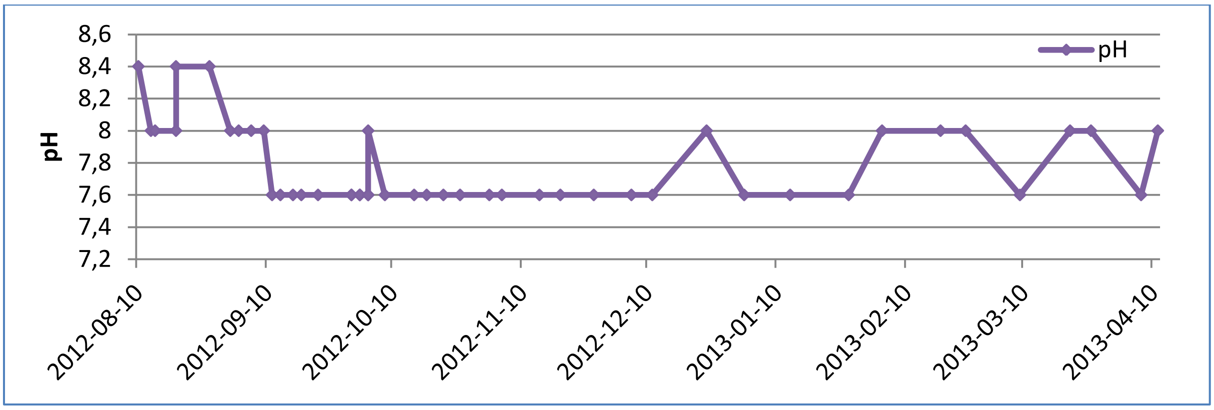

Figure 7 - Fish tank pH.

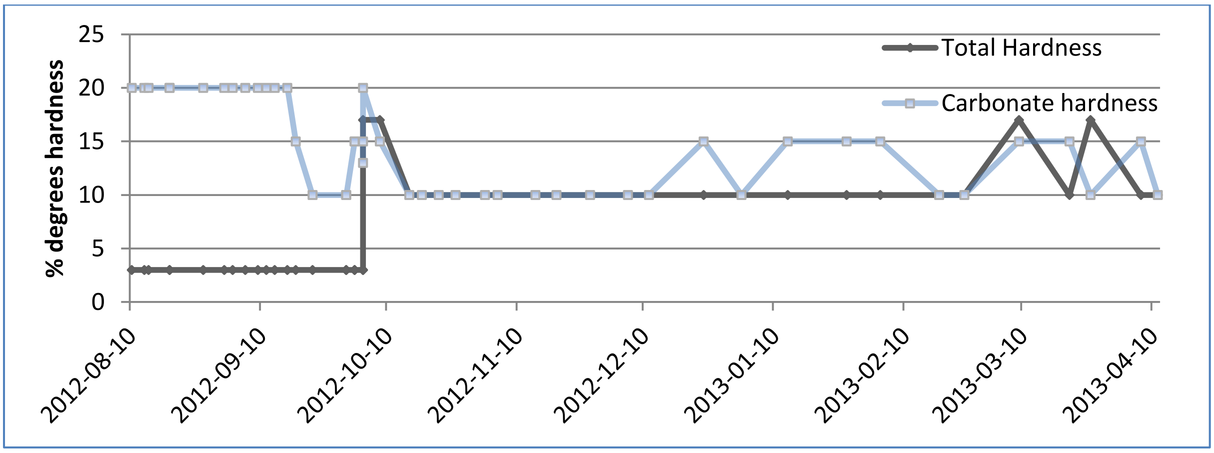

Figure 8 - Fish tank total and carbonate hardness.

November 16, 2012, I tested water from the fish tank for heavy metals and some other metals using an inductively coupled plasma mass spectrometer (ICP-MS). The reason for this measurement was to make sure that firstly no alarming metal-levels were present and secondly, if future issues were to befall the system several potential reasons hailing from high levels of metal could be removed from suspicion. The elements tested for was (Element, Chemical symbol):

Arsenic, As
Cadmium, Cd
Cobalt, Co
Chromium, Cr
Copper, Cu
Iron, Fe
Manganese, Mn
Nickel, Ni
Lead, Pb
Uranium, U
Vanadium, V
Zinc, Zn

The results are shown in table 2. The values are within the detection range except for iron, Fe, which showed a value of 0,1785 µg/l, which would have been fine like that, but as the measurement interval for iron is between 5 and 100µg/l any level below 5µg/l is outside the detection range. So the level of iron is, as such, below detection.

Based on limits and levels compared with external figures from LC50 research (Glenn and Suter, 1989) no alarming levels for brown trout were detected.

Table 2 – Aquaponic water sample ICP-MS results. Sampling date 2012-11-15. Date of analysis 2012-11-16.

Analyte	Detection range (in µg/l)	Concentration (in µg/l)
As	0.3 – 1000	3,6197
Cd	0,03 – 100	0,0378
Co	0,02 – 100	0,3209
Cr	0,2 – 100	1,1514
Cu	0,1 – 100	50,8714
Fe	5 – 1000	Below detection
Mn	0,3 – 100	2,5362
Ni	0,2 – 100	3,0573
Pb	0,3 – 100	0,621
U	0,05 – 100	0,1235
V	0,05 – 100	2,4381
Zn	3 – 1000	34,7916

3.3.4 Electrical energy

The electrical energy use for the water pump and LED light was calculated. The energy use for indoor heating is omitted in this study since this system was designed to work out of spare heat in a room already heated for other reasons.

The results (Appendix 1) are based on a one month use. The cost of the used electricity, bought from Jämtkraft, was very close to 1 SEK per kWh (retail price, including Swedish taxes and Value Added Tax).

The calculations added up to the following:

- The LED light use 7,2 kWh per month.
- The pump use 33,9 kWh per month.

In total, then, the system uses a total of 41,1 kWh per month and to keep this system running for this time costs slightly over 40 SEK. This is, obviously and as previously mentioned, a value omitting the spare heat in the room. It is rather clear, here, that the pump carries with it the majority of the cost.

4 Discussion

During this project I've come accustomed to the understanding that the aquaponic concept is not entirely new but it has yet to break the wall between theoretical science and some, select, elaborations and experiments into the grounds of "everyday life" and, for instance, industrial use.

4.1 My prototype

As I built the prototype and as a variety of matters occurred I learnt from them. From practical perspective it has been showed that it is possible to build and run a aquaponic system by an interested person. How the system was built, considerations during construction as well as practical experiences have been describe in some detail to make it possible to reproduce and improve by anyone

4.1.1 The fish tank

The trout's growth of only a few grams over six months may seem like a low number but keep in mind this is not something that increases in a linear fashion. This is made rather evident by looking at how trouts are usually kept in the aquaculture for two and a half to three years before harvesting, and have by then grown to a weight of several kilograms (Bonäshamn, 2013). Keep in mind that these figures, from the aquaponic, are based on the first version of a home-constructed system designed by only person. Here the results, in this first system-generation tryout, measures up to the conventional industry of today. It is important to keep in mind how every system adapts over time and quickly so early on, Adaptations in this system could, therefore, yield even better results given some more time and trial.

Another thing to put into context here is the matter of feeding. It is very likely an operating aquaculture, like the one I tend to compare some of my results to, feed the fish in a more fine tuned fashion. I fed the fish in my system in a very linear path, only increasing this very late in the process. It's likely that, to mimic the aquaculture, I would have been required to change into an even more suited type of fish feed as the trout grew. Due to this one could speculate if it would be possible that the trout growth would have been even better had the feeding been mirrored to the aquacultures. The trout's growth ties in closely to the financial possibilities of the system, which I'll touch upon in 4.2.

Did the overshoot of added ammonia result in a faster bacterial culture-growth? I have not looked further into this since it was somewhat out of scope. As I did not test it more than once I can't say I have definite proof, but the measurements do show a quick exponential increase of nitrite and nitrate (figure 6) in the tank. Levels too high for an aquaculture but perhaps it's a good way to kick start the growth of the necessary bacteria, and then replace the water, starting over with bacteria already present on the solid surface-areas in the tank. Having any "too high amount" of bacteria when starting with the newly replaced water is harmless since this water switch will force the amount of bacteria to change depending on the amount of ammonia they get, now produced by the fish.

When it comes to the ICP-MS results no alarming levels for this system were detected and no negative effects had been noticed on the fish. Therefore the system proceeding was not in jeopardy and maintenance was continued without adjustments due to these results.

When it comes to omitting the energy use for indoor heating it is important to note that: Should this system be incorporated on a larger scale in a building intended for this alone, heating will naturally be something to include. However, since a certain heating still takes place in conventional aquacultures today and as such already holds a compartment in the total of required energy I deem that it is omitted without further trouble.

4.1.2 The Growbed

As plants kept growing, gaining a beautiful green color and sprouting flowers it seems the plants did get what they needed nutrient vise. Of course, some species fared better than others as already explained (see 3.3.2) but unless some of the plant-species are evidently more sensitive to a lack of any specific micronutrient, this did not seem to be an occurrence due to a lack of micronutrients. I was, however, unable to delve deeper into this. The best example, pointing in my direction, would be the Oregano's adaptation and growth.

To grow a crop we are often, in conventional farming, used to monoculture crop growth. That has been shown to carry with it a number of negative, long lasting, effects on the soil and the volumes of harvest (Pimentel *et al*. 2005). Some of these effects could potentially be alleviated in an aquaponic growbed. Even though an aquaponic growbed is different from farm land it is still assailed by many of the same aggressors. That's to say that for the very same reasons showing us that an increased variation of species provides field with heightened response diversity this applies for a growbed as well. A field, just like an aquaponic growbed, lacking in species shows to be more prone to suffer the consequences of complications related to insect, bacterial and fungal infections. We can witness how, when an aphid infection such as the one impinging my system assail a growth, their potential for spreading is magnified in a monoculture. Since all adjacent plants are then of one and the same species, and of the approximate same age, the manner of which they are infected is retained equal. This has, at least previously and in conventional farming, called for the use of pesticides, which down that path was proven to be harmful to plants, animals and humans as well. When we speak of aquaponics, a system where it is very important that the balance of its inner workings is not interrupted, the use of pesticides falls to be hazardous for the entire system due to their upsetting of that balance. This leads us to state that, firstly, pesticide-precaution is essential, and secondly, a monoculture of plants should be prevented in the interest of a sustainable growbed.

This was clearly exemplified when my system was infested by aphids. They swarmed and wore down certain species of plants, for example different types of lettuce and strawberry-leaves, while they stayed completely clear of the different species of herbs, rosemary, thyme and oregano. This left me bereft of some plants, sure, but they did not wither my entire growbed, and they did not interrupt the balance enough to harm the fish tank. Had I grown but one crop, even one that did not get assailed by aphids, it's very likely that, if not the aphids, another infestation would have indirectly posed a severe threat for the fish. Since had the plants died the system that, among other things, purifies the water would have ceased to work. Building an aquaponic is, of course, a symbiotic mimicry of one of nature's cycles. Not only are we mimicking its function but it seems we are also mimicking its resilience based on how well we copy it. For an aquaponic growbed I here argue that the issue of a declined biological diversity stands as one of the most severe threats for its prosperous growth. Even though perhaps risking a dose of induced pharisaism of quoting myself, I will quote one of my works from former years that I feel points at the complexity and importance of biodiversity: "*The biological diversity of our nature, and the enormity of its importance, is something we are still only tapping the surface of. The immeasurable chains of dependencies and necessities are, truly, for us something easy to unbalance but almost impossible to mend.*" (Carlsson et al. 2012)

4.2 Financial considerations

Then we touch upon the financial aspect. A part that ought to be mentioned when discussing this is the electricity requirement. Here, in this system, the pump was the major consumer of electrical energy compared to the required energy for the light. A swift calculation would show that a couple of grams of growth per fish over six months, and a pump consuming close to 35 SEK per month translates to a rather high price per kilogram of fish. Since the pump accounted for the majority of the electrical energy consumption it is rather clear how it would be important to optimize the efficiency in water pumping in a large-scale facility. My pump, in the prototype, was not optimized. It could have powered a larger system. It is also very likely that an aquaponic system would not require more pumping than in an aqua culture as the fish in both cases are in constant need of oxygen. So, if aquacultures work financially, so should an aquaponics, at least in regard to pumping energy. But it is important to continue the work with it, especially in matters of optimizing and rooting out issues that tend to follow novelties.

Fish growth is greater in the later stages, if the fish continue to grow in a similar pattern as in Bonäshamn aqua culture. This is, of course, another thing that would fare well with further investigation. This experiment only witnessed six early months of fish growth. The figures between, say, month 24 and 36, in a continued experiment, would look vastly different and more in favor for a lower price per kilogram of trout.

In short, the experience from this study is that the aquaponic system should be aligned in order to optimize for fish growth seeing how trouts thrives well here. According to the numbers they thrive equally or even a little better here than they do in a conventional aquaculture. This should be subject to further investigations.

The project in place in Härnösand was touched upon in chapter 2. I soon found that the project and their results were not of immediate use for this study, due to two major reasons. First of which; as this project does not seem to strive for a systematic maximization – which from my side is intended to have its potential examined without any deteriorating result – of fish growth. As they say themselves "*In our little system it is not that important that the fish and plants grow at a maximum*" (Kattastrands kretsloppsodling, 2012) whereas I argue that, according to my results in 3.3.1, a systematic improvement to maximize fish growth and keeping vegetable growth as an added benefit falls well in line with our latitude position. The second reason is, quite simply, due to the fact that the information about this project reached me late in the process of this experiment. This rendered me unable to delve deeper into potential answers gained, or otherwise benefit, from it and thus no input from it formed any basis for the construction of my system. Another major difference is that their system, at times, operated in higher temperatures than mine did and they did not cultivate the same species of fish but rather koi or goldfish. Species not very prominent here in our waters, which would more evidently imply how their venture did not focus on fish growth. In total their amount of produced vegetable reportedly weighs 10 to 20 times their amount of produced fish. Depending on the price of the vegetable in question and the price of the fish this could be used as a framework for disseminating an economical result, this should be investigated in further studies. As for such figures, and compared to my results, it seems these figures looks “in favor” for vegetables as figures from growth of koi and goldfish will not likely resemble those of trout-growth. As this, in general, is a European Union-project with a goal to develop and demonstrate the possibility to use aquaculture together with plants in places where there is a lack of water I’d say that their results is unfitting or are hard to make use of as they have different goal.

4.3 Potential for aquaponics on northern latitudes

Here remains, what is my opinion after this year, the very possible opportunity of a technological conversion for aquaculture fish farming with similar, or better, yield than the conventional methods. Here is shown a very real possibility in converting current trout aquacultures to circulate their water instead of using freshwater from local watercourses only to swiftly discharge it back in a polluted state. Such a conversion could decrease negative effects this industry imposes on the surrounding aquatic natural environment. The only water needed to be added would be that lost due to evaporation. No polluted or overly nutritional water flowing back to the watercourse, thereby preventing eutrophication and the disruption of balance. By embracing the volition of turning to an aquaponic posture the water used to grow the trouts will be constantly cleaned by plants. These plants would then provide a possibility for added cash flow and goodwill. Perhaps it would open up ideas for products where both the trout and its seasoning were grown at the same place, with the help of each other. All in all such a system, an aquaculture moving towards aquaponic system thinking, would make much better use of the elements pulled in to it and waste much less by circulating them to where they are needed.

With some imagination one could find potentials in this such as the combination and co-operation of two heavily impacting sectors here. An aquaponic system fitted aquaculture where the water is kept clean and filtered by the growing spruce saplings meant for replanting clear cuts by the forestry sector. Now, spruce has not been tried in this experiment but I believe it would work quite fine seeing how the other species fared, which did best. Including the Norfolk Island pine, although not closely related they share at least a few similarities. At least I deem it worth investigating how spruce and trout could complement each other. After all they do belong to the same biome.

The results of this venture clearly show how the trouts in the aquaponic kept up with, and even surpassed, the trouts left in the aquaculture from where I got them. The same brood, the same batch, weighed more, six months later, having grown in the aquaponic system. The difference was minimal, but I’d say that provides an added layer of guarantee the values had a high level of security.

Trout do seem to grow very natural in a system like this one which can work as an economic favor should we choose to employ such observations. Out in nature they only grow during summer where as winter cause them to remain in a kind of “growth-stasis”. In the aquaponic they keep growing, as the conditions for them are always as if it was summer. I have not compared these figures with another aquaculture such as one situated directly in a lake. A similar, further developed, venture like this one but compared to such would likely prove interesting. There the reduction of environmental impact could be considered even greater. Especially if the case is an implemented aquaponic system-thinking producing a higher yield.

As the trout grows at least just as well in this system, or even better, this would mean that an aquaponic system-thinking could be used as an alternative way of constructing aquacultures imposing less stress on the surrounding nature as no water is released out into lakes or streams. By doing so we would also gain a new area of possibilities, economic or otherwise, from the growing vegetables.

Regarding the plants it seems like, out of the edibles grown here, some herbs grew best as they brought with them the least amount of problems and kept thriving. With oregano, for instance, blooming, sprouting and growing throughout the winter. As for the vegetables, this would open up for very real opportunities to prolong the very short growth season of our northern summers as this would indicate that aquacultures also contain an agricultural side. Of course, this might demand a higher energy demand in terms of heating, which translates into another variable to keep in account. A heated greenhouse added above the aquacultures fish tanks.

4.4 Flamboyant ideas

If the heating issue is solved, perhaps through a clustering of one or more other sectors, industries, it would be rather easy to disseminate various advantages. We can view a few potentials in the forest industry drying stations. Now and again, surely, there sips out waste heat. Or do they use everything?

If not, this could be a potential combinatory solution tying this together with aquacultures. One could profit by allowing the heat to pass there instead of where it goes today. Examples where excess heat has been used to heat houses are locally present and such a solution could therefore easily be used for heating an aquaponic. Another combination, or an added combination to this, could be another, a new, top floor on the local water reservoir "*Arctura*". A top floor consisting of a fish tank with surrounding growbeds! That is; designed as a tourist attraction with a clear sense of purpose.

I'll also argue that the results in this report lies as an advantage for several of the arguments raised by Aquabest, in their presently ongoing project which goal is to develop a "climate neutral" aquaculture within the Baltic region (Aquabest 2013), managed locally by the regional council of Jämtland county. It also shows how this concept would close several loops before problems would ever have to surface. Their suggested limits are already in intention of being breached by aquaculture investors it seems like, yet again, boundaries will be pushed and the environmental stress fall to be regarded as of secondary importance.

I could even be so bold as to suggest an opportunity where aquaponic system thinking could stand, not only as a ways to produce food and/or plants. But also as a way to filter, purify and produce oxygen. It's likely not needed on the surface of earth, but perhaps down underneath? In deep caves, in mines? Or in underwater research areas? Or perhaps even on the Mars One mission going off in 10 years that so far have only considered hydroponic solutions (Mars One, 2013). To begin with a hydroponic solution might be the best choice, but in time it might very well serve well to partially shift towards an aquaponic solution. I don't know this, but reasoning somewhat suggest that perhaps that would be a way to commence a slow terraform and thus the reintroduction of an atmosphere containing decent amounts of oxygen? Now, as far as I know Mars One do not plan for terraforming, as of yet, but later on. But, for now, let's return to earth. Further outside the scope of this thesis would be harder to reach, I realize as much. Daring? Yes, very. But it point to areas where this sort of system thinking is yet to commence.

I realize the sudden turn of views from a small scientific project about growth turning into an interplanetary concept, while flirting with comedy, still seem out of place in a bachelor thesis. But even so, allow yourself to question *everything*. We shouldn't stop considering new ideas before they are researched and tried even if there's but a slim chance of it working!

Now, to round things off before reasoning and idea-crafting runs amok.

4.5 Concluding discussion

A major obstacle for an economically feasible "pure aquaponic" in northern Scandinavia seems, to me, to be the recurring specialization that is what we have become accustomed to in our society. A system that provides more than one type of produce seems alien, and is likely to be shunned. Therefore, the idea has a hard time to surface, or is precipitously dismissed without being examined deeper. I believe this is a major and current impediment for aquaponics. The problem is not whether it works or not, because it does. But until habits change and this idea is no longer prejudicially dismissed there remains an idea, as previously mentioned, of using aquaponic system thinking when constructing aquacultures, if nothing else as an outlet for excess aquaculture water to pass through a rich growbed, consisting perhaps of herbs – Thereby opening up for new possible cash flows – before its release to a lake, stream or whatever body of water is its intended goal. Or, for the same reasons, convert existing ones. Further research in areas such as this would likely do well with mass balance calculations in attempt to ascertain whether or not a certain system yields and works well enough and if so how to potentially maximize the desired yield in terms of aquatic life and vegetables. The fish grows in a slightly higher rate during the entire year – instead of only a rough half of months as is the case in aquacultures situated directly within lakes and the likes – and there is little stress on surrounding nature resulting from residues of fish and food waste. To adequately measure this further investigation would be required, but even so it holds a high potential in our climate thanks to the natural conditions and circumstances surrounding local game fish, such as trout, which here tends to be a desired species for cultivation.

5 Conclusion

A small scale aquaponic system was constructed. The start up and running of the system was followed over 9 months. The fish species grown in the fish tank was trout. The plants in the growbed were a mixture, with herbs as a dominating part. Water from a local well was used. At start, appropriate nitrogen level in the system was achieved by adding ammonia.

The values of nitrate, nitrite, pH, carbonate and total hardness were analyzed in repeatedly measured samples. The values stabilized quickly and stayed stable during the duration of the experiment. Heavy metals were analyzed at one point in time and showed no levels causing reason for alarm. Electric energy use for pumps and lighting was estimated to reach close to 40 kWh per month.

The trout growth was monitored and found to be comparable with (equal or slightly higher than in) the conventional aquaculture, where the fish were originally obtained, when comparing with the same species and same brood.

Among flora three herbs were the species thriving best, Oregano, Rosemary and Thyme. They kept growing throughout the winter with Oregano never ceasing to bloom. The total mass of produced vegetables and herbs were fairly low, since the herbs grew best.

Results indicate that present aquaculture systems (fish only) could potentially be converted or adjusted into aquaponic systems (recirculating and purifying the water through a growbed) and thereby decrease potential risks of fresh water pollution from fish farming, especially regarding excessive nutrients.

From the results in this study, aquaponic systems on northern latitudes seems to be better off if focusing on fish growth, with herbs or vegetables as added benefit, and not focusing on maximizing vegetable growth.

Further studies should investigate optimization parameters and identify optimal mixture of plants over the year.

6 References

Aller Aqua, 2013. "Fish Feed - Aller Performa" Available at: http://www.aller-aqua.com/cms/front_content.php?idcat=410&changelang=3 [Accessed 2013-06-04]

Aquaponic Lynx LLC, Aleece B. Landis, "Fishless cycling". 2010. Available at: http://www.aquaponiclynx.com/fishless-cycling [Accessed 2012-07-28]

Glenn W., II Suter. 1989, *Aquatic Toxicology and Environmental Fate: Eleventh Volume*, Pennsylvania. ASTM International.

James E. Rakocy, R. Charlie Shultz, Donald. S Bailey, Eric S. Thoman. 2004. "Aquaponic Production of Tilapia and Basil: Comparing a Batch and Staggered Cropping System", *Acta Horticulturae*, (no, 648 February 2004).

James E. Rakocy, Michael P. Masser and Thomas M. Losordo. 2006. "Recirculating Aquaculture Tank Production Systems: Aquaponics—Integrating Fish and Plant Culture". Available at: http://www.aces.edu/dept/fisheries/aquaculture/documents/309884-SRAC454.pdf [Accessed 2012-06-22]

James E. Rakocy. 2010. "Beware of Aquahysters", *Aquaponics Journal*, no. 58 (Quarter 3, 2010).

Kattastrands kretsloppsodling, 2012. "To balance the production of fish/plants". Available at: http://www.rainbowfish.se/english/f90.htm [Accessed 2013-05-20]

Manahan, Stanley. 2010, "*Environmental Chemistry*", Boca Raton. CRC Pres.

Mars One, 2013, "FAQ - Health and Ethics", Available at: http://mars-one.com/en/faq-en/20-faq-sustainability/253-will-the-astronauts-have-enough-water-food-and-oxygen [Accessed 2013-05-11]

McMurtry, Mark, and Sanders, Doug. 1988. "Fish Increase Greenhouse Profits", *American Vegetable Grower*.

McMurtry, Mark, and Nelson, Paul. V.; Sanders, D, C.; Hodges, L. 1990. "Sand Culture of Vegetables Using Recirculating Aquacultural Effluents". *Applied Agricultural Research* 5, no. 4 (1990).

National Institute for Fusion Science, Theory and Computer Simulation Center, Shiego Kida, "*Life, Structure, and Dynamical Role of Vortical Motion in Turbulence*". 2001. Available at: http://www.igf.fuw.edu.pl/IUTAM/ABSTRACTS/Kida.pdf [Accessed 2013-04-21]

Oxford Dictionaries, "*Aquaculture*", http://oxforddictionaries.com/definition/english/aquaculture?q=aquaculture [Accessed 2013-03-25]

Oxford Dictionaries, "*Aquaponics*", http://oxforddictionaries.com/definition/english/aquaponics [Accessed 2013-03-25]

Oxford Dictionaries, "*Hydroponics*", http://oxforddictionaries.com/definition/english/hydroponics?q=hydroponics [Accessed 2013-03-25]

Oxford English Dictionary, "*Aquaponics*", http://public.oed.com/the-oed-today/recent-updates-to-the-oed/previous-updates/september-2012/new-words-list-september-2012/ [Accessed 2013-03-25]

David Pimentel, Paul Hepperly, James Hanson, David Douds, and Rita Seidel. 2005. “Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems”. Washington DC; American Institute of Biological Sciences.

Play with Water, 2007. “*Play with Water: Introducing Ecological Engineering to Primary Schools to Increase Interest and Understanding of Natural Sciences*”. Available at: http://www.play-with-water.ch/ [Accessed 2013-05-20].

Regional council of Jämtland County. Project information AQUABEST; http://torsta.se/wp-content/uploads/2012/12/projektbeskrivning_aquabest1.pdf

Robert F. Raleigh, Laurence D. Zuckerman, and Patrick C. Nelson. 1986. “Habitat Suitability Index Models and Instream Flow Suitability Curves: Brown Trout”. Colorado State University. Available at: http://www.nwrc.usgs.gov/wdb/pub/hsi/hsi-124.pdf [Accessed 2013-05-20]

Rydén, Lars. 2003. “*Environmental Science*”, Uppsala. Baltic University Press.

The Free Merriam-Webster Dictionary, “*Aquaculture*”, http://www.merriam-webster.com/dictionary/aquaculture [Accessed March 25, 2013-03-25]

The Free Merriam-Webster Dictionary, “*Hydroponics*”, http://www.merriam-webster.com/dictionary/hydroponics [Accessed March 25, 2013-03-25]

University of Rhode Island. 1999. “*Aphids, Homoptera: Aphididae. GreenShare factsheets*”. University of Rode Island Landscape Horticulture Program. Available at: http://www.uri.edu/ce/factsheets/sheets/aphids.html [Accessed 2013-05-20]

Wikipedia, “*Aquaponics*”, http://en.wikipedia.org/wiki/Aquaponics [Accessed 2013-03-25]

Wilson Lennard. 2009. “Aquaponics: The Integration of Recirculating Aquaculture and Hydroponics”, *World Aquaculture* 40, (no. 1 2009).

Wilson Lennard, 2012 “Aquaponic System Design Parameters: Media Beds and Sizing”, *Aquaponic Solutions*. Available at: http://www.aquaponic.com.au/Media%20beds%20and%20design.pdf [Accessed 2013-05-20]

Unpublished work

Bonäshamn Aquaculture, 2013. Available for communication at Vattenregleringsföretagen, Kyrkgatan 21, 831 25 Östersund, Sweden. Aquaculture located in Bonäshamn, Åre Municipality. Discussion about management, trout weighing and methods. [visit & phone call] (Personal communication, 18 October 2012 & 25 April 2013).

David Carlsson, Mikael Nordfjäll, Maud Roset, Robert van Sloten, Susanne Tellström. 2012. “*Forestry in Sweden – To retain biodiversity & how this became an issue*”, Department of Engineering and Sustainable Development, Mid Sweden University.

7 Appendix

Appendix 1 – Electrical calculations

Calculations simplified and added here for the sake of transparency. The price per kilowatt hour was gained from an invoice's details. It ended up just below 1 SEK per kWh, which I'll use to calculate cost.

The LED light, Growspot, use 15W.

16 hours per day x 30 days = 480 hours per month

16h*15w = 240 Wh. (~24 Swedish öre),

240 Wh * 30 days = 7,2 kWh per month. Ca. 7,20 SEK.

The pump use 400w.

2 minutes per pumping, then waits 15 minutes. That is: One cycle = 17 minutes

1440 minutes per day / 17 = 84,7 cycles per day

84,7 cycles * 2 minutes = 169,4 min/day

169,4 * 30 = 5082,4 minutes per month => 84,7 hours per month

400*84,7 = 33880 = 33,9 kWh per month. Ca. 34 SEK.

In total this amounts to 7,2 + 33,9 = 41,1 kWh per month to a cost of ca. 41,1 SEK. Slightly over 40 SEK.