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Aquaponics: Economics and social potential for sustainable food production

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Aquaponics: Economic and Social Potential

For Sustainable Food Production

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Abstract

Aquaponics is a soilless agriculture system that combines hydroponics and aquaculture to grow both fish and produce. Aquaponics relies on a recirculating closed loop system that can allow for a 90 – 97% reduction in water usage compared to irrigation in convention agriculture. Aquaponics also greatly reduces the possibility of water contamination because there is no runoff. The energy investment in agriculture can also be greatly reduced through the low energy fertilizer source presented by the fish. When used as a local food source aquaponics also has the benefit of reducing food miles, improving food security, and participating in the development of local economies. While aquaponics is largely unfeasible in the developing country context at this time due to the system's complexity and underdeveloped supply and support infrastructure there are growing possibilities for implementation in urban settings. Urban aquaponics can be implemented in commercial, community based, and personal systems, while the focus of this study is commercial based approaches.

Two different production systems were considered in this study. The UVI system (University of the Virgin Islands) is a more traditional approach to commercial aquaponic production that emphasizes aquaculture and utilizes raft production techniques. It requires substantial equipment investment and higher operational expenses. Although it can provide very high outputs its commercial viability may be constrained by the availability of a suitable market for the fish. The Bright Agrotech system emphasizes produce production and utilizes a vertical, media filled, tower based system. The Bright Agrotech system requires lower investment and operational costs and may be viable for a broader range of markets. Strategies for improving the commercial viability of aquaponics are discussed along with a comparison to the viability of purely hydroponic systems. It is concluded that aquaponics should be classified as a lifestyle business or social entrepreneurship and slow growth of the industry is expected in the short term future due to competition with hydroponics for the same mark segments.

What is Aquaponics

Aquaponics combines the agricultural processes of hydroponics and aquaculture into a single, closed loop, food production system. To fully appreciate how aquaponics functions it is essential to understand the component systems that it is built from.

Hydroponics

Hydroponics is more prevalent than aquaponics and it has become common in commercial greenhouse agriculture since its introduction over 40 years ago. It is often referred to as soilless agriculture because in these systems plants are grown in a nutrient solution without soil. The nutrient solution contains all the essential macronutrients and micronutrients for growth, which are usually optimally balanced for maximum productivity. Because of the precise control and optimal conditions hydroponic growers can typically bring crops to harvest much faster than growing in soil. It is also possible to have a yearlong growing season with greenhouse techniques, allowing growers to provide fresh produce out of season (Sheikh, 2006). Also hydroponically grown plants are often claimed to be of higher quality and have better taste than conventional agriculture.

Hydroponics is often promoted as a highly sustainable form of agriculture and a key method for meeting the food demand of the world's rapidly growing population. In addition to its quick crop cycling and extended growing season its benefits include

- Significant reductions in water usage
- Higher efficiency allowing for more plants per square foot
- No detrimental effects on soil quality
- Reduced use of herbicides and pesticides due to the controlled environment
- Reduced fertilizer requirements compared to conventional agriculture (Sheikh, 2006)

In particular water and space efficiency are two of the most important benefits of the system allowing for food production in urban areas where water and space are both a premium. Hydroponics can reduce water usage between 90 and 97% compared to soil based agriculture (Sheikh, 2006). This is particularly attractive with the high rates of urbanization and population growth. It can also serve to preserve soil quality in areas where poor farming practices have degraded the environment.

One hurdle for hydroponic production is its high capital cost, in particular for the greenhouse and growing system (Kruchkin, 2013). Because its production method is very similar, aquaponics offers all of the benefits of hydroponic production and also shares many of its challenges.

Aquaculture

Aquaculture is the practice of farming fish and other aquatic animals in a controlled environment, and it is separate from commercial fishing which only includes wild catches. Aquaculture has grown substantially over recent decades to meet the rising demand of seafood, as the wild catch has remained consistent. By 2030 it is expected to provide approximately 50% of the global fish supply ("Opportunity for Expansion: Aquaculture in Canada: Canadian Aquaculture Industry Alliance," 2012). Aquaculture has the promise of supplying the ever increasing demand for seafood while maintaining our ocean's fish populations. However there are environmental and health concerns with aquaculture.

Marine aquaculture has been known to produce high levels of organic wastes, eutrophication, and increased nutrient concentrations in surrounding bodies of water. This is a result of high concentrations of fish waste that are an inevitable output of aquaculture (Kruchkin, 2013).

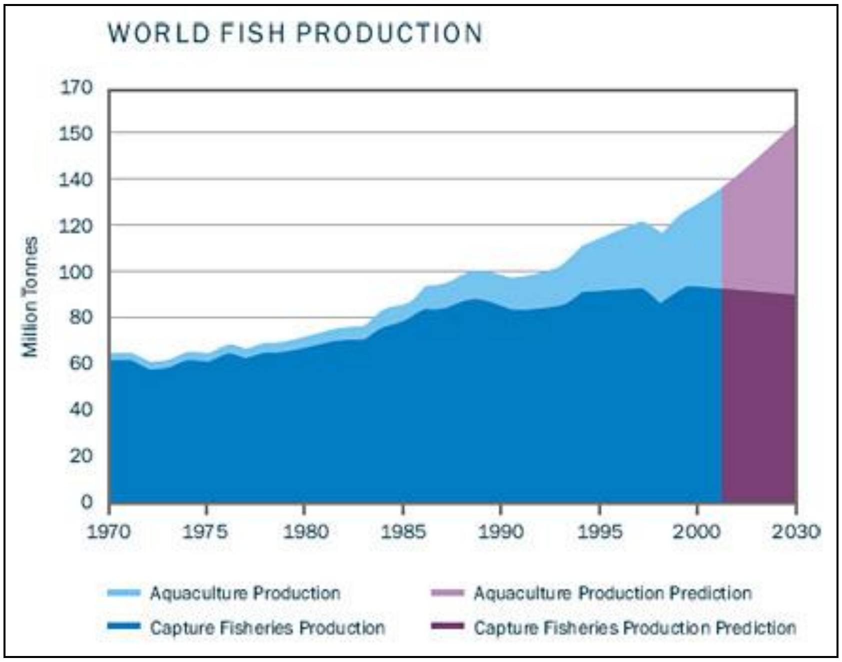

Figure 1. Projected growth for aquaculture in 2030
Source: www.aquaculture.ca/files/opportunity-expansion.php

Aquaponics

Aquaponics balances the inputs and outputs of aquaculture and hydroponics to form a closed loop system that produces both fish and produce. The fish are grown in tanks that circulate the water and fish waste to the plants. The plants use the waste as their fertilizer and the fresh water is circulated back to the fish. The major nutrient circulated through the system is nitrogen, and because of this the driver for any aquaponic system is nitrifying bacteria. Nitrogen is excreted from fish in the form of ammonia, which is both toxic to the fish and unusable for the plants. Nitrifying bacteria convert ammonia to nitrite and then to nitrate. Nitrates are highly bioavailable and are the preferred form of nitrogen for plants and are also nontoxic for fish.

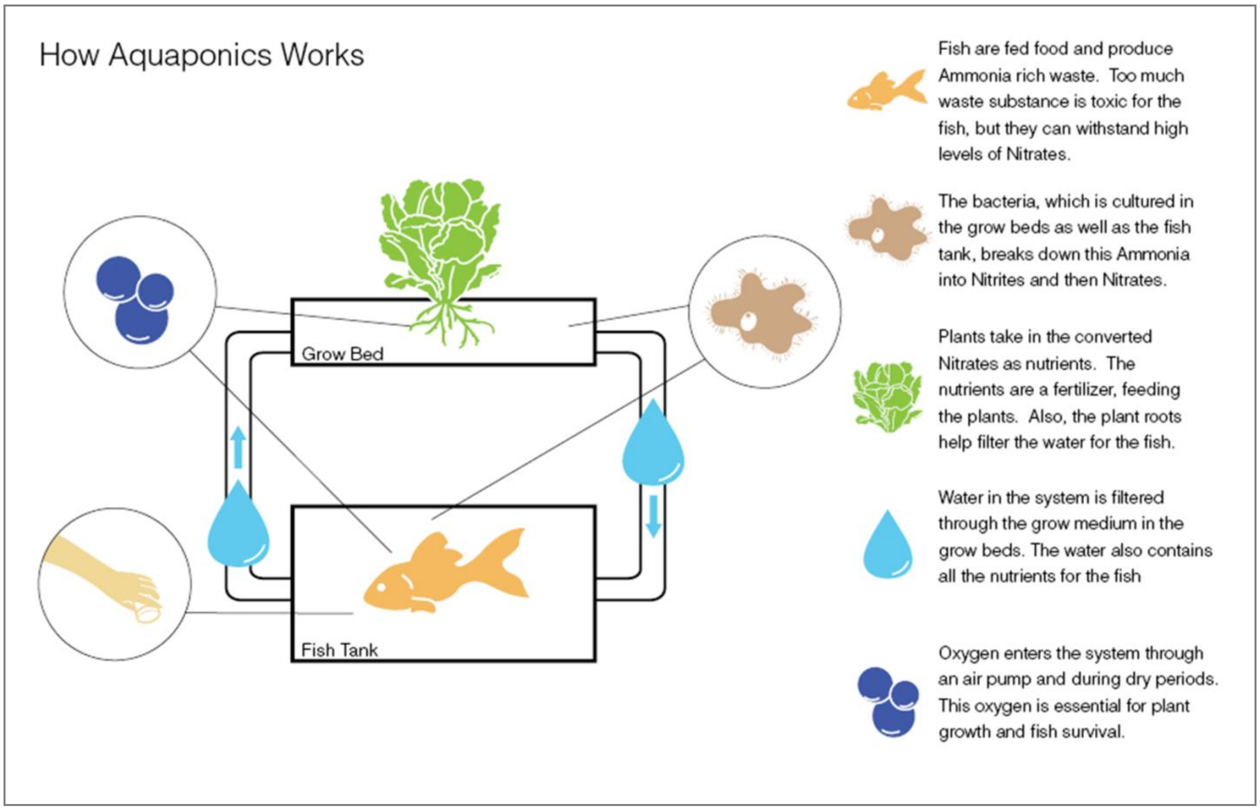

Figure 2. Overview of the aquaponic process
Source: http://wisdomniu.wordpress.com/page/46/

Technical Overview

Unlike hydroponics aquaculture involves maintaining an ecosystem inside the system which requires due consideration in system design and operation.

System components.

Every aquaponics system is composed of the following components

- Fish tanks
- Hydroponic units
- Pump
- Sump tank (may not be present in small systems)

While there is little significant variation in fish tanks there is a large diversity in hydroponic units (Sheikh, 2006).

Raft production.

Raft systems are the traditional production method for large scale aquaponic and hydroponic operations because of its high production yields, simple design, and low cost (Sheikh, 2006). Plants are grown in polystyrene sheets (rafts) which float on top of the nutrient solution. Plant roots hang down directly into the water. Raft systems are the most water intensive hydroponic unit because of the large volume of standing water. In raft systems 75% of the water can be located in the hydroponic units while in other systems the majority of water is located in the fish tanks (Rakocy, Masser, & Losordo, 2006).

Figure 3. Examples of raft production systems
Source: http://aquaponicsplan.com/setting-up-your-own-aquaponics-system/

http://aquaponics.com/page/methods-of-aquaponics

Nutrient Film Technique (NFT).

In NFT systems plants are grown in long, downward sloping channels where the nutrient water flows through as a thin film. Plant root tips are kept in the film while the tops are kept moist. NFT systems are not as common in commercial scale aquaponic systems as they are in hydroponics (Sheikh, 2006).

Figure 4. Examples of NFT production
Source: http://aquaponichowto.com/aquaponics-nft/#.U2ZiYoFdWSo
http://www.marleypipesystems.co.za/marley-pipe-news/343-nft-hydroponic-systems

Media Systems.

Media based systems grow plants in a media to increase biological surface area for improved nitrification. Media materials can include perlite, rockwool, sand, crushed granite, or synthetic fiber matrixes (Sheikh, 2006)(Storey, “Biological Surface Area in Aquaponics,” 2013). A common problem with media systems is fouling from accumulated solids so beds may need to be stirred between crop yields (Rakocy, Masser, & Losordo, 2006). The nutrient solution can be supplied either as a continuous trickle or in and ebb and flow method where the bed is periodically flooded and then allowed to slowly drain (Rakocy, Masser, & Losordo, 2006).

Figure 5. Examples of media bed production systems
http://aquaponics.com/page/methods-of-aquaponics.
http://www.aquaponicsresourcecenter.com

Vertical Systems.

As their name implies vertical systems allow for plant production in three dimensions, which can be used to maximize growing space. The nutrient solution is pumped to the top of each grow tower and it flows down to each plant. Vertical systems can rely on a nutrient or media based method.

Figure 6. Examples of vertical production systems
Sources: http://vancouverislandaquaponics.com/learn/farmphototour#prettyPhoto
http://www.thedailycity.com/2012/10/the-green2ouse-lunch-and-tour-shows-off.html

Sump Tanks.

Sumps are used to recollect all the solution water after it has passed through the hydroponic units (or fish tank if reversed) and then pump it from a single point back to the top of the system. Sumps are typically where supplemental chemicals are introduced to allow for mixing and dilution outside of either growing or fish raising areas (Rakocy, Masser, & Losordo, 2006). Systems should only rely on one pump regardless of size to reduce failure points and prevent an overflow of water in either the fish tanks or hydroponic units which could result in crop losses (Storey, "One Pump vs. Two Pump Aquaponic Systems," n.d.). The importance of this is stressed by aquaponics researcher James Rakocy in his quote "One God, One Country, One Pump".

Aquaponic systems may require additional components in addition to those described, these additional components will be covered in the UVI system section.

System Mechanics.

Nitrification is the chemical process that drives aquaponic systems. In nitrification ammonia (NH_3) is converted into nitrite (NO_2^-) by the bacteria in the genus *Nitrosomonas* which is then converted to nitrate (NO_3^-) by *Nitrobacter* bacteria (Rakocy, Masser, & Losordo, 2006). While ammonia is highly toxic to fish and not readily available for plant absorption, nitrates are an optimal nitrogen source for plants and are not toxic to fish except in high concentrations (Storey, "Aquaponic Plant Nutrients: Nitrogen," 2013). Maintaining adequate nitrification levels is achieved through proper system design and operation. Within the nitrification process is a second important nitrogen balance. Ammonia in solution is constantly moving towards equilibrium with ammonium (NH_4^+), which is significantly less toxic than ammonia. Ammonia dominates the equilibrium at high pH ranges and ammonium dominates at low pH ranges with a even mixing point around pH 8 (Storey, “Ammonia & Aquaponics,” 2013). This system is in conflict with nitrification in aquaponics as nitrification is most efficient at high pH (Storey, “Ammonia & Aquaponics,” 2013). Striking a balance between nitrification and a beneficial ammonia : ammonium ratio is important to running productive system.

Biological Surface Area (BSA) is a key factor that influences nitrification and determines how productive a system can be. BSA is a measure of the available surface area in a system that that nitrifying bacteria can grow on (Storey, “Biological Surface Area in Aquaponics,” 2013). Total system BSA is measured in ft^2 and the specific BSA of different media is measured in ft^2/ft^3. Surface area is directly proportional to a system’s nitrification rate and a low BSA will lead to fish toxicity and plant nutrient deficiency. There are no negative consequences with excessive BSA. Raft systems are more likely than media based systems to be deficient in BSA due to the high surface area associated with media and an additional biofilter may be required for raft systems to ensure proper nitrification (Rakocy, Masser, & Losordo, 2006). Proper sizing of BSA is critical in the design of any system. The minimum recommended amount of BSA in a system is 2.5 ft^2/gal, although 5-10 ft^2/gal is beneficial especially in establishing systems (Storey, “Biological Surface Area in Aquaponics,” 2013). Included are the specific BSA and void ratio for common aquaponic media options.

Media	Size (Inch)	BSA (ft^2/ft^2)	Void Ratio
Medium Grade Sand	0.12	270	40%
Pea Gravel	0.57	85	28%
¾ crushed granite	0.75	45-60	35%
River Rock	1.0	21	40%
Zip Grow	N/A	260-290	91%

Table 1. The specific BSA and Void Ratio for various aquaponic media (Storey, "Biological Surface Area in Aquaponics," 2013)

BSA is a direct consideration in the stocking density of the fish in an aquaponic system which is measured in lbs of fish / gal in the fish rearing component of a system. High stocking densities, around 0.5 lbs/gal are used for commercial aquaculture and commonly when combined with water intensive hydroponic units (raft production) in an aquaponic system (Rakocy, Masser, & Losordo, 2006). Lower densities, down to 0.1 lbs/gal can be used in lower water intensity units (NFT and tower production) (Storey, "Aquaponics Stocking Density," 2013). High stocking densities require aerators and solid filtration systems as seen in the UVI system (Rakocy, Masser, & Losordo, 2006).

Stocking density and water temperature have a large impact on the dissolved oxygen (DO) in a system. As with all dissolved gases DO concentration is inversely related to temperature, which can be problematic as fish metabolism increases with temperature increasing the demand for oxygen (Storey, "Aquaponics & Dissolved Oxygen: The Basics," 2012). Maintaining high DO is essential for fish health and nitrifying bacteria populations. Low oxygen levels can lead to anaerobic digestion in parts of the system which can result in methane (CH^4) and Hydrogen Sulfide (H_2S) production and subsequent plant and fish losses (Rakocy, Masser, & Losordo, 2006). Sharp dips in DO can often result from decaying organic matter lodges somewhere in the system and it should be addressed quickly (Storey, “Aquaponics & Dissolved Oxygen: The Basics,” 2012).

Mineralization is a second chemical process that operates inside of aquaponic systems. Bacteria on plant roots and other surface areas collect and metabolize fine and suspended solids that result from the fish producing other minerals and nutrients necessary for plant growth (Rakocy, Masser, & Losordo, 2006). Because of this even systems utilities extensive solids filtration equipment need some solids circulating through them.

Nutrient Balance.

Nitrification and mineralization produce sufficient amounts of the essential nutrients necessary for healthy plant growth including nitrogen, phosphorous, copper, and zinc among others. However deficiencies can still occur and nutrient supplementation is often required in aquaponic systems.

Iron is a common nutrient that needs to be supplemented in any aquaponic system. Iron can be present in two forms ferrous iron (Fe^{2+}) which is soluble and ferric iron (Fe^{3+}) which will precipitate out of the solution. For plant absorption iron needs to be in its ferrous form and chelating agents are used to ensure the iron is bioavailable (Storey, “Iron in Aquaponics,” 2013). Fish toxicity can be an issue with chelating agents and for this reason FeEDTA is not recommended, FeDTPA and FeEDDHA are preferred sources (Storey, “Iron in Aquaponics,” 2013). The UVI system recommends using 2 mg/L (7.58 mg/gal) of iron dosed every 3 weeks, however this can also be broken up in weekly doses (Rakocy, Masser, & Losordo, 2006).

Potassium, Calcium, and Magnesium can also exhibit deficiencies in aquaponic systems. While any of these nutrients can be deficient separately they often have overlapping interactions because all three are present as positive ions in the system (K^+, Ca^{2+}, Mg^{2+}) (Storey, "Potassium in Aquaponics (Part 2) - Potassium in Your System," 2014)(Storey, "Calcium in Aquaponics," 2014)(Storey, "Magnesium in aquaponics," 2014). Plants can have difficulty recognizing and absorbing the proper ion balances even if sufficient levels off all nutrients are present because the nutrients can outcompete each other. Potassium is the most likely to be deficient, calcium deficiencies are also very common and is magnesium a less common issue (Storey, "Potassium in Aquaponics (Part 2) - Potassium in Your System," 2014)(Storey, "Calcium in Aquaponics," 2014)(Storey, "Magnesium in aquaponics," 2014). When managing these nutrients it is necessary monitor both their overall concentrations as well as their relative ratios.

Objective of Study

The objectives of this study are as follow

1. Investigate the sustainability benefits of aquaponics in regard to water conservation, food security, greenhouse gas emissions, and community development
2. Investigate the potential of aquaponics in the context of developing countries and urban areas

3. Investigate commercial scale systems and how their design impacts commercial viability
4. Generate conclusions on the commercial viability of aquaponics and predict future growth of the industry

Sustainability Benefits

Aquaponic systems have numerous benefits for social and environmental sustainability. These benefits stem from the recirculating nature of the system and production of local food.

Benefits of Closed Loop Design

The main environmental benefits of aquaponics result from its closed loop design with the outputs of aquaculture becoming the inputs for crop production. Water conservation is greatly increased compared to conventional agriculture. As with hydroponics, aquaponics produces equivalent crop yields using only 3-10% of the irrigation water used for industrial agriculture (Sheikh, 2006). Water is only lost through evaporation and any necessary water exchanges (Rakocy, Masser, & Losordo, 2006). This may be the most crucial benefit of aquaponics as population growth and economic development are greatly increasing water stress. Agriculture is estimated to account for over 60% of global water demand and this will only increase (Richardson, 2012). Additionally much of this water comes from nonreplenishable aquifers such as the Ogallala aquifer in the United State's Midwest (Brown, 2013). The depletion of these aquifers will greatly reduce or eliminate agriculture in many of the world's great crop producing regions. In order to deal with these inevitable shortages technologies such as aquaponics and hydroponics must shoulder a greater portion of crop production where appropriate.

Aquaponic's closed loop design also contains all the nutrients within the system, preventing any runoff or water impairment that has been a major issue with conventional agriculture. The US Environmental Protection Agency (EPA) has estimated that 70% of all stream and river contamination is from industrial agriculture (Richardson, 2012). It also has the potential for lower nutrient inputs (fish feed and supplements instead of fertilizer), especially if water exchanges are minimized.

Additionally the recirculating system enables the symbiotic relationship between the fish and bacteria which provides nitrates for the plants. This relationship eliminates the need for synthetically manufactured fertilizers which are typically produced through the energy intensive Haber-Bosch process ("An Energy-efficiency Lead for Nitrogen Fertilizer Production," 2013). This reduces the embodied energy input for the system, helping to reduce greenhouse gas emissions. This benefit can be further increased by using low energy, locally sourced fish feed options.

Finally, the recirculating system eliminates the need for soil. This greatly increases the area we have available for food production and allows the implementation of high yield systems in high population centers. The advantages of bringing food closer to people are discussed in the following section.

Benefits of Local Food Production

Aquaponics can realize its full sustainability potential when used for local food production. These benefits can be realized by any form of local food production however compact, soilless systems such as aquaponics are uniquely adapted to urban environments.

By bringing aquaponics into population centers food miles, the distance food travels from production to consumption, are greatly reduced. This reduces the fossil fuels and subsequent carbon emissions from food distribution. For modern agricultural this averages to 1,600 miles for vegetables and 2,400 miles for fruit, and distribution accounts for 7-11% of the carbon emissions from agriculture (Richardson, 2012). Bringing food into urban areas also increases food security. Large cities are dependent on agricultural centers hundreds or thousands of miles away and rely on interconnected networks of interstates, rail, and shipping to supply their food demand (Bach, 2013). Local production increases the self-sufficiency and resiliency of large urban centers.

Local food production also has direct benefits for the communities they are developed in, especially if they are in economically disadvantaged areas. Aquaponics and other forms of local and urban agriculture can stimulate the local economies they are based in through the creation of jobs, increased tax revenue, and recirculation of dollars coming into the economy. A study that investigated the economic impacts of increasing local food production to 25% of demand in the greater Cleveland economic area could create over 27,000 new jobs corresponding to $868 million in income, increase regional output $4.2 billion, and increase tax revenue by $126 million. However these benefits are not necessarily low hanging fruit and that $1 billion in investment capital would be necessary along with policy adjustments and consumer education (Richardson, 2012)(Masi, Schaller, & Shuman, 2010). Community systems such as Growing Power in Milwaukie, WI facilitate community interaction and development through volunteer programs and revitalizing underutilized space (Spirn, 2011).

Local food production through aquaponics and other means can play a role in reducing food deserts. Food deserts are areas where residents do not have access to fresh, nutritional food options. The USDA identifies an area as a food desert if it meets the following conditions.

“Census tracts qualify as food deserts if they meet low-income and low-access thresholds:

1. They qualify as "***low-income communities***", based on having: a) a poverty rate of 20 percent or greater, OR b) a median family income at or below 80 percent of the area median family income; AND

2. They qualify as "***low-access communities***", based on the determination that at least 500 persons and/or at least 33% of the census tract's population live more than one mile from a supermarket or large grocery store (10 miles, in the case of non-metropolitan census tracts).” (“Food Deserts,” n.d.).

Figure 7. Counties with high concentrations of food deserts
(Richardson, 2012)

In food deserts these options are replaced by large fast food chains, contributing to many negative health consequences for the residents in those communities (Richardson, 2012). Developing aquaponic operations in these locations could provide access to healthy sources of produce and protein.

Developing Countries

Early in this investigation developing countries were identified as a social group that may benefit greatly from aquaponics. Individuals and communities alike could benefit from a reliable source of food production however there are several barriers that make implementation of aquaponics in this context unfeasible at this time.

Experience of Users

Aquaponics requires a fairly large amount of knowledge to run successfully. To successfully implement aquaponics in developing countries growers would need extensive training and education on topics that may be unfamiliar to them such as pH, nutrient levels, and the nitrification process. Additionally users would need to be trained in water techniques and have access to appropiate equipment.

Water Quality

Access to appropriate water sources may be an issue in many situations where rain water collection is not sufficient. Local water sources may contain high turbidity levels, not meet pH requirements, or contain other compounds that would impair the system. In stressed areas aquaponics could create tension between drinking water resources and food resources.

Capital Costs

The high capital cost of aquaponics is also prohibitive as many families and communities will not be able to afford the systems. Alternatives to this would require a scheduled payback strategy or constructing systems out of salvaged materials. In this case growers would likely need assistance in designing a functional system.

Supply Infrastructure

Growers would need access to distribution networks in order to receive supplies as the systems require nutrient supplementation and periodic fish restocking. At this point such infrastructure is not available to many of these areas. Growers could utilize local sources of fish feed but it may be more difficult to accurately control nutrient levels with a variable feed source.

Electricity

As aquaponic systems rely on electric powered pumps to function insufficient access to an electrical grid further complicates the problem. This may be the easiest problem to overcome as many alternative strategies have been developed systems could be powered by photovoltaic panels or by mechanical wind powered pumps (Hughey, 2005).

Future Potential

Because of the constraints listed above aquaponics does not appear to be an effective strategy for improving quality of life for the disadvantaged in developing countries. Due to the constraints discussed, system crashes would be very likely resulting in wasted resources and diminished trust in aid solutions for the affected communities. As these countries develop further aquaponics will become more feasible and it may have a large role to play in future development.

Urban Application

Bringing agriculture into urban settings is tantalizing for its food security and sustainability benefits. Aquaponics has the potential to do very well in urban environments because of its space efficiency and ability to grow produce without soil. Aquaponics can provide a means to bring healthy vegetable and protein sources into urban spaces usually devoid of these options. There are three main ways aquaponics can be implemented in urban areas that we will cover in this chapter.

1. Commercial Systems
2. Nonprofit and Community Systems
3. Personal Systems

Commercial Systems

Commercial aquaponic production in urban areas has the potential to produce large quantities of food in urban areas and is particularly attractive because it is a financially sustainable model. Commercial aquaponics has the ability to repurpose underutilized or unused space in cities such as rooftops and abandoned warehouses. Unfortunately to this point there has been a very high failure rate for commercial aquaponics both inside and out of urban area, calling its viability into question. Several distribution strategies and common reasons for commercial failures are listed below.

Distribution Models

CSA.

In a CSA (community supported agriculture) customers pay an upfront cost to receive a predetermined share of the farm's yield every week. Memberships length can vary anywhere from three months to a full year. The CSA is advantageous to farmers for several different reasons. Most importantly it guarantees income from a particular customer for several months, helping to stabilize weekly income and reduce the need for farm to market itself once the CSA reaches a desirable level. The sales for this period are received upfront which helps to free the business's cash flow. Another benefit is the sense of comradery created between the growers and the consumers. Members of a CSA often feel that they are a part of the growing process, sharing in both the risks and rewards of the farm. This relationship often gives members a sense of loyalty to the farm. Operating a CSA can help increase flexibility in an aquaponic grower's business model and assure adequate profit margins, especially in the early stages of development.

Farmers Markets.

Farmers markets have increased rapidly in the United States with the growth of the local food movement. In general this bodes well for aquaponics as it gives growers another means to directly market their target consumers in a location where their local and sustainable qualities will be well received. However the large growth of farmers markets has created a disparity and some markets are highly successful while others do not draw significant crowds due to location and other factors. Aquaponic growers should be careful to place themselves in markets where they will have the opportunity to meet their sales quota (MacNear & Keller, 2012). Additionally growers should look to place themselves in exclusively food markets if possible because customers are focused specifically on their food needs. Membership in a farmers market will require interviewing with a market manager and detailed operational plans may be necessary

(MacNear & Keller, 2012). Typical membership fees include an annual charge for floor space and a small percentage of all sales.

Grocery Stores & Food Retail.

Marketing to supermarkets in high population areas and large store chains are difficult as these operations have large distribution networks involving wholesalers and highly competitive contracts. Conventional supermarkets are cost focused and as such rely on a large distributor or several that can provide all the products for a store (Barron et al., 2010). In some cases where a single distributor is not used over 200 suppliers may distribute to one store (Barron et al., 2010). These distributors are often responsible for both the selection and delivery of products. Even organic focused stores which are quality focused and rely on their own set of distributors meet their stocking needs. In this noise it will be difficult for aquaponics to establish contracts with the majority of food retailers and distributors as cost competitiveness will likely reduce the profit margins to an unsustainable point except for very large scale operations. Additionally distributors and wholesalers may be wary of working with aquaponic growers due to concerns over consistent system production and commercial viability. Aquaponics may be able to score contracts with local focused stores however the success and limits of this approach are entirely dependent on the store and local market conditions.

Restaurants & Food Service.

As with grocery stores restaurants rely on suppliers and distributors for the vast majority of their needs. These suppliers are common to almost all restaurants in a given location depending on weather they are quality focused or cost focused (Barron et al., 2010). Local sources are only a concern in local focused restaurants. Aquaponics will have difficulty penetrating this market for the same reasons as retail markets; however there are possibilities for partnerships with local focused restaurants.

Reasons for Failure

Not Designed for Profitability.

Several commercial aquaponics operations have failed because they are based off inherently unprofitable systems. There are several well-known community based aquaponic systems which operate as a nonprofit entity (discussed in next section). These operations hold trainings as a way to fulfill their mission and generate additional income (Spirn, 2011). Several entrepreneurs have based their commercial systems off of the community systems presented at these trainings which has repeatedly resulted in failure (Bach, 2013). In this case entrepreneurs equate biological viability with commercial viability (Storey, 2012). While the biological viability of aquaponics has been well documented commercial viability has been far more elusive. These failures gain significant attention in the aquaponic community so the number of aquaponic producers attempting to commercialize this system should decrease dramatically.

Inappropriate Scaling.

Entrepreneurs often start their systems too large or scale them too quickly to reach advantageous economies of scale. While scaling is important starting with a large system greatly increases the likelihood of a crash. Young systems can take a year or longer to fully establish and diversify its bacterial populations system ecology. As such systems in early phases are more fragile and more likely to crash than older systems (Storey, “Aquaponics System Cycling,” 2013). Running a large system or scaling on quickly adds additional strain during this period. Adding high production quotas places additional strain on the business and making a mistake is very expensive at a large scale (Storey, 2012). To compound this several entrepreneurs have attempted commercial aquaponics after switching careers and only possessing experience with personal, small scale aquaponic systems (Jones, 2013).

Underestimation of Expenses.

Entrepreneurs often underestimate labor expenses associated with commercial systems, especially during the establishment phase. In addition to planting and harvesting systems must be monitored and adjusted to maintain proper nutrient balances. Additional new systems are prone to leaks and clogging as operators become accustomed to the system and address flaws from construction (Richardson, 2012). Growers who do not utilize an owner operated model in which they participate in running the system will face greatly increased costs (Cavaliero, 2013). When budgeting it is possible that entrepreneurs assess labor based on experience small scale systems or use estimates from established systems. Growers may also come into the industry with expectations of spending the majority of their resources to marketing. Dr. Nate Storey from Bright Agrotech says that 90% of his time is spent selling and 10% is spent growing (Storey, 2012). Energy and lighting requirements for greenhouses in northern latitudes also contribute significant expenses as seen with the Vertigrow investigation (See attached Vertigrow Business Plan).

Inadequate Pest Control.

Much of the literature surrounding aquaponics discourages the use of chemical pest control strategies for the danger it poses to fish (Rakocy, Masser, & Losordo, 2006). However, after consulting with professional greenhouse growers this does not appear practical in greenhouse production (T. Hayden, Personal communication, October, 2013)(B. Plummer, Personal communication, October, 2012). This has been supported by Tim Hayden, CEO and founder of Shenandoah Growers and Bob Plummer, Vice President of Agricultural at Shenandoah Growers. Multiple pesticides should be used because pests can acquire immunity if one control is used repeatedly (Storey, "Pest Controls for Aquaponics," 2013). Growers should not take the effect to fish lightly and should ensure they can tolerate whatever method is used and strictly follow dosing instructions. Pest control is further covered in the Bright Agrotech case study chapter.

High Capital Costs.

Aquaponics is highly capital intensive which requires growers to seek out investors and sources of debt (Kruchkin, 2013). Not achieving expected yields due to a previously mentioned mistake or other factor will cut into a grower's profitability and may impair their ability to pay back their debt, forcing the business to go under.

Community & Nonprofit Models

Community systems can achieve similar production environmental sustainability benefits as commercial aquaponics although they are not finically sustainable on their own. However these systems can achieve greater social benefits compared to commercial systems because they actively involve community members and give them a stake in their food production.

The most notable community system is Growing Power based in Milwaukie, WI and founded by urban farming advocate Will Allen. Growing Power is registered as a nonprofit organization has over 30 different revenue streams including produce and fish sales, trainings, research grants, university partnerships, and experimental production techniques such as dipping logs into the nutrient solution to grow shitake mushrooms (Spirn, 2011). Although committed to providing its employees adequate incomes to live comfortably Growing Power also benefits from high volumes of volunteer labor (Spirn, 2011).

Although not the focus of this investigation community models should be viewed as a viable alternative method for achieving the benefits of aquaponics where financial viability is not possible. Cities and communities may wish to invest in community aquaponic systems to increase food security, empower disadvantaged communities, provide jobs, increase property values, and achieve all the environmental benefits even though the system may not directly pay for itself.

Figure 8. Photograph of Growing Power's system
Source: http://en.wikipedia.org/wiki/Growing_Power

Personal Systems

Personal aquaponic systems can achieve great sustainability implications because they provide users with the ability to grow a portion of their food right in their home. Entrepreneurs may be able to find success in this market if they are able to develop simple systems that are ascetically appealing. In some urban areas residents may be able to implement small scale systems if they have adequate lawn space. In high density areas the most practical approach may be micro-scale systems that can fit on a counter. At this scale system maintenance could potentially be non-existent.

Startup company Back to the Roots is already pioneering this space with their product AquaFarm, which they advertise as a self-cleaning fish bowl that can grow a small amount of greens (“AquaFarm,” 2014). Although still a very small market personal systems have the potential to yield large sustainability gains.

The UVI System

The UVI system was developed and has been extensively studied at the University of the Virgin Islands for which it is named. Designer Dr. James Rakocy designed it for supplementation of inland aquaculture operations to reduce filtration equipment and provide additional revenue streams (Rakocy, Masser, & Losordo, 2006). As such the UVI system emphasizes high stocking density (0.5 lbs/gal) and raft aquaponics (Rakocy, Masser, & Losordo, 2006). This is the traditional model for commercial aquaponic production. A schematic of the system is pictured below.

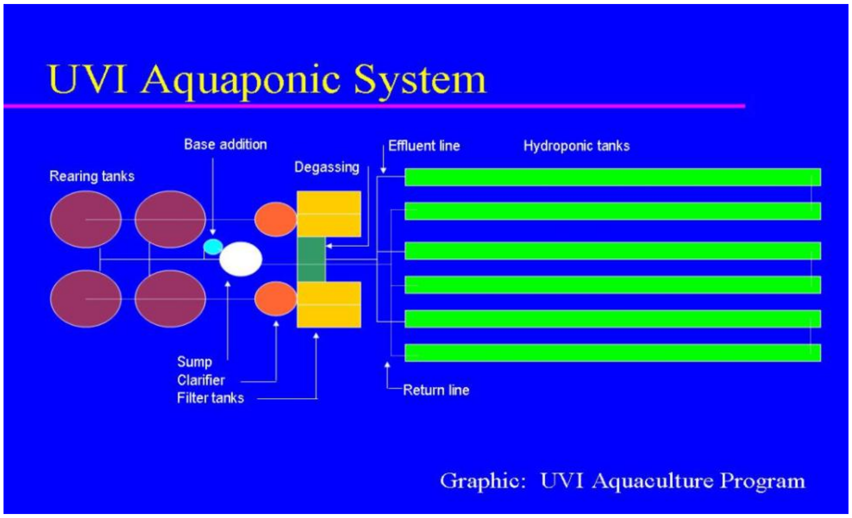

Figure 9. Schematic of the UVI growing system
Source: http://en.wikipedia.org/wiki/Growing_Power

The UVI system is entirely gravity fed after water is pumped from the sump tank to the fish. Fish are grown in several large rearing tanks as seen to the left of the diagram. Each rearing tank is 2,060 gallons and can hold 1,000 talipa (Rakocy, Masser, & Losordo, 2006). Fish are raised in the same tank until harvest and are all removed at once and replaced with a new crop. The harvesting of each tank is staggered so that every tank is in a different phase of production (Rakocy, Masser, & Losordo, 2006).

Other harvesting strategies exist but this is recommended to reduce fish stress from changing tanks or sorting, prevent undersized from remaining in the system due to size based sorting methods, keep feeding rates and nutrient consistent across the system, and maintain consistent harvesting schedules for suppliers. Although not pictured the UVI system utilizes aerators to supplement into the fish tanks and maintain DO because of the high stocking density (Rakocy, Masser, & Losordo, 2006).

After water overflows from the depth regulator in the fish tanks it passes to the filtering equipment which includes two clarifiers, two filter tanks, and two degassing chambers. This stage is necessary because of the high solids content resulting from the high stocking density. Otherwise the solids would foul in the hydroponic tanks producing methane and hydrogen sulfide which would result in a catastrophic system crash (Rakocy, Masser, & Losordo, 2006). The clarifier removes settable solids and must periodically be emptied. The filter tanks catch suspended solids with orchard and must be cleaned 1-2 times per week. The degassing chambers are necessary because solids accumulate on the orchard netting and begin to degrade anaerobically producing methane and hydrogen sulfide which must be vented before water flows to the hydroponic tanks (Rakocy, Masser, & Losordo, 2006).

In this schematic the water is split three ways on its way to the hydroponic tanks. Each tank is 4' x 100' and holds 3,000 gallons of water at 16'' depth to provide fop a 2,304 ft^2 growing area (Rakocy, Masser, & Losordo, 2006). The water flows down one tank, overflows to an adjacent tank, and then flows back towards the center of the system. Aerators are also included in the raft tanks to maintain DO (Rakocy, Masser, & Losordo, 2006). Each polystyrene sheet is 8' in length and production is sequential with crops moving along the tank as it grows. Sheets are harvested at the end of each tank and replanted at the beginning. Again other strategies exist but this is recommended to reduce labor in harvesting and replanting, maintain consistent nutrient absorption across the system, and maintain consistent harvesting schedules for suppliers (Rakocy, Masser, & Losordo, 2006).

All water collects back into the sump tank and a ½ hp pump returns the water to the fish tanks at a rate of 100 GPM. A separate base addition tank is connected to the sump tank which serves as an extra dilution step for the sodium hydroxide (NaOH) which is added to maintain the system's pH at 7.0 (Rakocy, Masser, & Losordo, 2006).

Because it has been extensively studies specific calculations have been developed to calculate system sizing based on the required demand for fish or produce. The UVI system uses a feed conversion ratio of 1.7 to determine feed requirements based on the mass of fish produced (Rakocy, Masser, & Losordo, 2006). The necessary feeding rate to support raft aquaponics is between 60 – 100 g of feed / m^2 of plant production / day. If less water intensive hydroponic systems are used the feed requirements can be reduced by 75% (Rakocy, Masser, & Losordo, 2006). These calculations are beneficial to entrepreneurs because it can provide appropriately designed systems to meet market demand.

Figure 10. Photograph of the UVI system in the Virgin Islands
Source: http://www.wrongwayhome.com/2012/05/aquaponic-system-final-design/

Bright Agrotech Case Study

To further assess the viability of commercial aquaponics a case study was performed on Bright Agrotech LLC. Bright Agrotech is a midsize aquaponic producer operating a 400 tower vertical system in Laramie Wyoming. CEO Dr. Nate Storey founded the operation after completing his doctorate in Aquaponics and Novel Agricultural Businesses Models. It was selected as the subject of a case study for three reasons.

Figure 11. Bright Agrotech logo
Source: http://www.brightagrotech.com/

Profitability – As many aquaponic ventures have been unsuccessful this was the first priority in choosing a business to analyze

Unconventional – Bright Agrotech flips the traditional commercial aquaponic model on its head, making it both an intriguing subject and giving it the potential to expose shortcomings in the traditional model

Accessibility of Information – Bright Agrotech maintains a video blog, web blog, and holds webinars explaining their system. Additionally Dr. Nate Storey was open to holding several phone interviews

Technology

Bright Agrotech's system is based off of its patented ZipGrow tower and media technology. The ZipGrow towers are composed of a rectangular plastic sheath that holds a fibrous matrix media. The media is folded lengthwise within the sheath so that the opening between the two halves aligns with a slit that runs lengthwise down the sheath. Seedlings are planted within the two halves of the media and the roots grow and anchor between the fibers. Nutrient water is pumped to the top of each tower and trickles by gravity through the media. Although Bright Agrotech runs both its farming operation and ZipGrow sales under the same entity Dr. Storey assures they are both self-supporting ventures (N. Storey, Personal communication, October, 2013).

Vertical System.

With its tower technology Bright Agrotech uses a vertical system meaning that it has a much lower water intensity than the UVI system. It allows for growing in three dimensions which allows Bright Agrotech to make use of its limited greenhouse space. Their spacing density is one tower per every 2.25 - 2.5 ft^2 (Storey, "Spacing ZipGrow Vertical Farming Towers," 2013).

Modular Units.

Unlike a raft or NFT system the vertical system is built from many towers put together. The light weight nature of these towers allows them to easily be removed and reinserted into the system. This allows Bright Agrotech to greatly expedite its harvesting and replanting processes.

Matrix Media.

The largest advantage of the ZipGrow technology is the matrix media held inside the tower. The matrix media provides many benefits to the aquaponic system. First it has an extremely high BSA on the order of 270 - 290 ft^2/ft^3. This allows Bright Agrotech's system to have very high nitrification rates. Second the media has a void ratio of 91% due to its fibrous nature (Storey, "Biological Surface Area in Aquaponics," 2013). This high porosity creates a highly aerobic environment for the plant roots and oxygen enrichment of the nutrient water trickling through the tower. It also allows for high percolation rates through the tower. Usually high BSA comes at the expense of porosity, such as in the case of sand. Combining both of these in the same media creates an optimal environment for aquaponic production. Additionally because of the aerobic environment solids can collect and decompose on the media without creating an anaerobic microenvironment.

Figure 12. Matrix media inside a ZipGrow tower
Source: http://brightagrotech.com/HobbyAquaponics.php

System Operation

Bright Agrotech runs their system in a way that is very different from the traditional UVI approach, which offers an alternative approach for entrepreneurs.

No Harvesting of Fish.

The starkest difference between the two systems is that Bright Agrotech deemphasizes their fish production to the point where they are not harvested and used only as a fertilizer source (Storey, "Aquaponics Stocking Density," 2013). While they do not generate any revenue from the fish they also incur several benefits from this production method. The first is greatly reduced equipment cost. Because they are not selling their fish they do not need to stock their fish at commercial densities. The difference is 0.5 lbs/gal in the UVI system to 0.1 lbs/gal in Bright Agrotech's system (Rakocy, Masser, & Losordo, 2006) (Storey, "Aquaponics Stocking Density," 2013). Nutrient levels in the plants are not affected because of the low water intensity of the ZipGrow towers. Their low stocking density combined with the oxygen enrichment in the ZipGrow towers allows Bright Agrotech to eliminate the need for aerators (Storey, "Removing Solids in Aquaponics," 2014). The low stocking density also eliminates the need for clarification, suspended filtration, and degassing since the matrix media can process the low solid load. As insurance Bright Agrotech maintains populations of red worms in their towers to break down solids and contribute to nitrification (Storey, "Removing Solids in Aquaponics," 2014). They also maintain high turbulence in their sump to mechanically break apart any large solids (Storey, "Removing Solids in Aquaponics," 2014). Eliminating this equipment reduces Bright Agrotech's capital investment and eliminates the labor and energy costs necessary to operate and maintain them.

Low pH.

Bright Agrotech runs their system in the 6.0 – 6.4 pH range. This is significantly lower than the 7.0 – 7.5 recommended in the UVI system. This lower range is the optimal range for plant production since soil is naturally acidic and it also maintains an advantageous ammonia : ammonium ratio (Storey, “Ammonia & Aquaponics,” 2013). By doing this Bright Agrotech has increased their plant productivity and reduced the threat of ammonia toxicity. Furthermore they have done this without sacrificing efficient nitrification. Aquaponic systems naturally acidify over time due to the nitrification process. Instead of maintaining the pH with the addition of bases Bright Agrotech has slowly let it decrease over time as their system established. Over this period the bacteria in their system adjusted to the change. Additionally the high BSA of the ZipGrow towers ensures that there is strong nitrification and a high number of bacteria initially to survive the transition.

Pest Control Strategies.

Bright Agrotech advocates using a robust pest control that includes beneficial organisms and organically certified chemical controls. Literature on the UVI system discourages chemical controls on account of its effects on the fish and many growers proudly assert their chemical free crops (Rakocy, Masser, & Losordo, 2006). Dr. Storey maintains that from a practical perspective greenhouse growing requires some method of controlling pests beyond beneficial organisms, as once an infestation is in place beneficials are no longer effective (Storey, “Bio Controls for Aquaponics,” 2013). To ensure it does not suffer a devastating outbreak Bright Agrotech employs beneficial ladybug and wasp populations to control background levels of aphids and other pests.

For greater protection Bright Agrotech alternates spraying several fungal mixes and ORMI certified organic products (Storey, “Pest Controls for Aquaponics,” 2013). To ensure the health of their system they do control dosage and avoid controls that will harm the fish.

Split System.

Bright Agrotech utilizes a split system design that provides water under pressure to both the fish tanks and grow towers with only one pump (Storey, “1-Pump Aquaponics Systems: Splitting Flow,” 2013). A diagram of the system and its flow is pictured below. Just as with the UVI system the pumped is located next to or in the sump tank. The line from the pump is then split between the fish tank and the grow towers where it returns back to the sump via gravity. The continuous mixing in the sump tank ensures that no part of the system is isolated (Storey, “1-Pump Aquaponics Systems: Splitting Flow,” 2013).

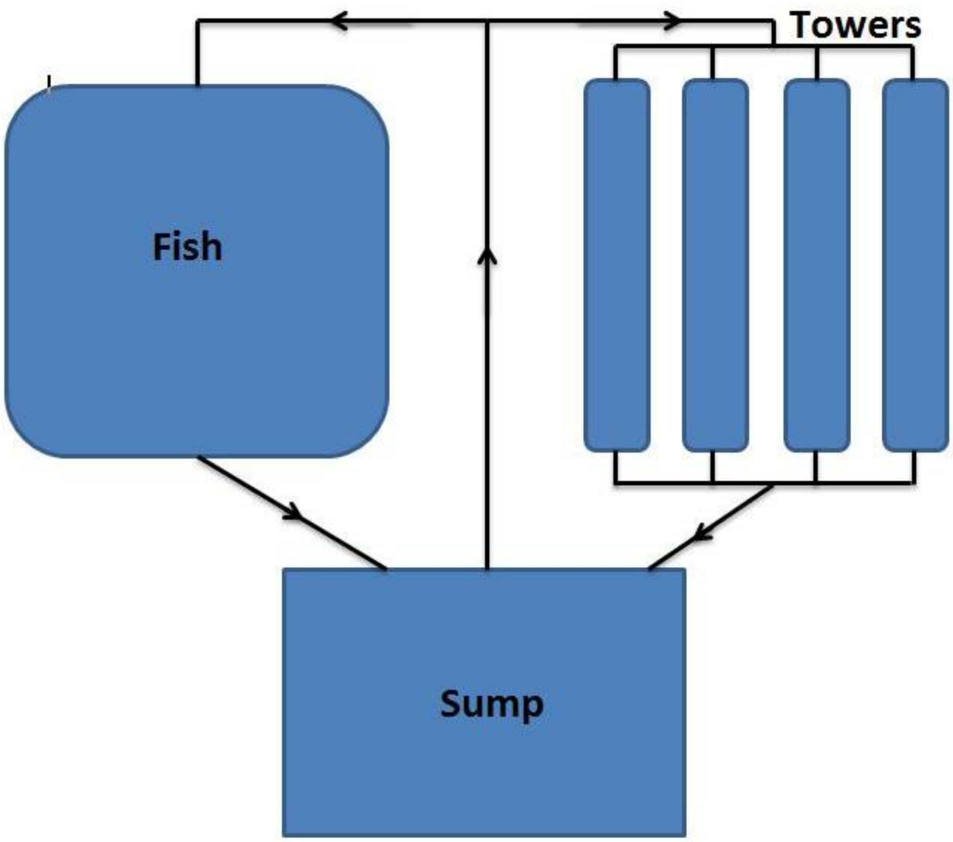

Figure 13. Schematic of the Bright Agrotech split system (Storey, "1-Pump Aquaponics Systems: Splitting Flow," 2013)

This design benefits Bright Agrotech in several ways. The most prominent is the facilitation in expanding their system. When Bright Agrotech decides to add more towers they only need to increase the output of their pump and adjust their throttles accordingly to deliver more water to the towers. Increasing tower size on a gravity fed system would be much more difficult and may require additional fish tanks (Storey, "1-Pump Aquaponics Systems: Splitting Flow," 2013).

Splitting the system also allows Bright Agrotech to isolate either part of their system if desired (Storey, "1-Pump Aquaponics Systems: Splitting Flow," 2013). This facilitates maintenance and cleaning of the system and it also acts as a measure of security. If there is a large pest outbreak among the plants and Bright Agrotech is forced to use a pest control that is harmful to their fish they can isolate the towers and only run water to their fish until it is safe to reconnect the towers. They also isolate the towers on very cold nights to reduce the cost of heating their water. If there is a crash in the fish population Bright Agrotech can drain the fish tanks to a reserve tank and run the towers as a hydroponic system until they have reestablished a stable fish population (Storey, "1-Pump Aquaponics Systems: Splitting Flow," 2013).

Business Model

In addition to their system operation and design Bright Agrotech has creatively approached their market and business model.

Live Sales Distribution.

Instead of packaging their produce Bright Agrotech has their customers pick their own produce right from the towers it is grown in (Storey 2012). This adds considerable value for their customers because they can interact with the produce and they know they are getting the freshest possible food. It also considerably reduces the processing and harvesting costs associated with distribution (Storey, 2012). To prepare their crops workers only need remove the tower from the system and rinse the tower. The customers actually harvest the produce reducing the labor costs for Bright Agrotech.

CSA.

Bright Agrotech utilizes a CSA distribution model to market directly to their customers. Bright Agrotech sells its CSA memberships in full and half shares. A half share runs $325 for six months and $553 for 12 months. Full shares run $500 for six months and $850 for 12 months (N. Storey, Personal communication, October, 2013). Running the

CSA allows Bright Agrotech to avoid competitive contracts with grocery stores and restaurants, and the loyalty created with a CSA helps ensure strong customer turnover.

Lateral Expansion.

Laramie is a small city with a little over 30,000 people. After reaching the market capacity of Laramie, Bright Agrotech expanded by investing in Bay Berry Herbs, a hydroponic farm in Denver, Colorado that uses the ZipGrow technology (N. Storey, Personal communication, October, 2013).

Conclusions

Bright Agrotech has designed a flexible system that reduces the necessary equipment and water intensity. Unlike the UVI approach they have developed a business model and system that emphasizes plant production. This may be advantageous due to the high output of produce relative to fish in aquaponics, both financially and physically. Bright Agrotech clearly analyzed their market and concluded that the additional costs investing in commercial aquaculture was not justified by the market in Laramie. Instead by optimizing produce production they have focused their effort on the most lucrative component of aquaponics and eliminated a large amount of capital costs and operating expenses. Additionally by increasing system flexibility they have addressed some of the shortcomings of the UVI system. Bright Agrotech is able to maintain finer control of the nutrient balance in their system by using the less water intensive tower system. The split system also facilitates a modular expansion which can serve as a model for other growers who want to start small and build up.

Bright Agrotech's innovations can provide a range of technology and system designs for growers in locations where a strict UVI system is not appropriate. Growers with access to larger markets may be able to combine the systems, expanding a small tower system and then investing in a raft system or expanding aquaculture once the system and market can bare it.

Figure 14. Dr. Nate Storey in the Bright Agrotech greenhouse
Source: http://www.brightagrotech.com/

Final Recommendations and Conclusions

Recommendations

What follows is a set of recommendations for current and prospective aquaponic growers to increase their systems commercial viability as seen from literature review, industry analysis, and the Bright Agrotech case study.

Determine Role of Fish Early.

As demonstrated earlier there are multiple ways fish can be implemented in an aquaponics system from simply a source of fertilizer as seen with Bright Agrotech to the high intensity production used in the UVI system. A careful analysis of the potential market for fish in your area will determine the system type and growing strategies necessary for a successful aquaponics operation. Growers need to determine if the market will bare the required fish densities to maintain the maximum produce a market can bare. For example a low demand for fish may not support a high demand for produce in a water intensive raft production system. Maintaining these additional fish simply to support the produce is a drain on the company’s resources, especially in the early phases while a system is being established. Knowing the market will allow growers to size and design a system that will be profitable for their market. Making these decisions early is essential to save time and prevent an investment into an unsuitable system. Additionally there is no reason why a grower can scale into fish distribution after their system and produce distribution is established.

Aggressively Reduce Expenses and Costs.

This is by no means specific to aquaponics however it is essential due to the high capital costs and low profit margins associated with the industry. As demonstrated with Bright Agrotech, creative market approaches can serve as a way to streamline the growing process and reduce costs associated with labor. CSA models can significantly reduce expenses for growers if approached correctly. In this case cost reduction strategies can be taken from non-profit operations such as Growing Power, even if the system itself should not be emulated by commercial growers. For example Growing Power utilizes internships from local universities to help reduce its labor expenses (Spirn, 2011). Land is often the largest capital cost for growers so specific care should be taken in selecting a location (See attached Vertigrow Business Plan). Unused warehouse or greenhouse space can often be converted for aquaponics. This is by no means a guarantee of success as many growers do this but is still important to consider.

Scale Business with Respect to System.

Starting with large scale production places strain on the system in two ways. First larger systems are more difficult to manage, especially during the establishment period of the system (Storey, 2012). This can be compounded when growers try to extract the large production quotas necessary to financially support the large system. The combination of this can lead to a system crash or failed operation. To mitigate this growers should expand their business with respect to their system. It is easier to start small and expand as the system establishes itself. While financially it is beneficial to move to large production capabilities to ensure profitability it is essential to recognize the biological limitations of working with an ecosystem approach. Ultimately a system crash or insufficient yields is more detrimental to a system in the long run (Storey, 2012). To ensure the success of a modular growth plan growers should make sure they have sufficient working capital and a strategic investor who understands the expected returns of an aquaponic venture (See attached Vertigrow Business Plan).

Weight Produce According to Profit Margin.

Crop selection for any agricultural venture is key to success. Aquaponic growers need to consider biological viability and profit margins for their system. Growers should analyze what their market will bear for each crop they plan to grow and set priority space in their system for the most profitable crops. Produce profit margins should be easy to determine for a specific area and a sample from the Virgins is included below. Herbs such as basil should play a part in every commercial aquaponic system because of their high profit margins (Storey, 2012). Although experimentation is encouraged growers should refrain from overproducing high profit crops or exotic and untested crops because unsold produce is a drain of resources and as such is worse than unused growing space (Storey, 2012). Additionally flooding a local market can reduce the price of your produce hurting long term viability (Rakocy, Masser, & Losordo, 2006).

Crop	Annual production		Wholesale price		Total value	
	lb/ft²	tons/2690 ft²	Unit	$	$/ft²	$/2690 ft²
Tomatoes	6.0	8.1	15 lb	17.28	6.90	18,542
Cucumbers	12.4	16.7	2.2 lb	1.58	8.90	23,946
Eggplant	2.3	3.1	11 lb	25.78	5.33	14,362
Genovese basil	6.2	8.2	3 oz	5.59	186.64	502,044
Lemon basil	2.7	3.6	3 oz	6.31	90.79	244,222
Osmin basil	1.4	1.9	3 oz	7.03	53.23	143,208
Cilantro	3.8	5.1	3 oz	7.74	158.35	425,959
Parsley	4.7	6.3	3 oz	8.46	213.81	575,162
Portulaca	3.5	4.7	3 oz	9.17	174.20	468,618

[1]Ecomonic data based on Calgary wholesale market prices for the week ending July 4, 2003.

Table 2. Returns for different produce options

Integrate Multiple Revenue Streams.

Multiple revenue streams help to provide resiliency to an aquaponics operation in case of a system crash (Cavaliero, 2013). Successful operations such as Bright Agrotech and Greenacre Aquaponics combine system sales, trainings, and consulting with produce sales (Cavaliero, 2013). It is important to note that multiple revenue streams should not be used to finance an unprofitable system but to enhance profitability for the owner and act as insurance for an already successful system. In this case cues may again be taken from non-profit systems such as Growing Power, which incorporates shitake mushroom production into its system. However growers should be careful to verify that the time and labor associated with incorporating an additional revenue stream into their system is justified by its economic returns.

Vertigrow Conclusions

Vertigrow is a business concept for an urban based hydroponic farm that was developed in conjunction with this report. The original plan for Vertigrow was to design a business plan for an aquaponic system, however during the course of the investigation it became apparent that operating a hydroponic system was more financially viable. Hydroponics was chosen so that a more feasible business plan could be presented. Explained here are the reasons why hydroponics was found to be more financially viable than aquaponics.

Capital Costs.

Aquaponics involves higher capital costs than hydroponics because of the additional equipment necessary. This includes fish tanks and potentially clarifiers, solids filter, degassing chamber, biofilter, and aerators. Additionally investments must be made in stocking the system with fish. This needs to be done on a regular basis unless fish rearing is done on site, which requires additional capital. As hydroponics is already considered a capital intensive industry these additional investment costs required higher debt loads and further strain on cash flow (See attached Vertigrow Business Plan).

Labor.

As identified earlier labor is a major expense in aquaponics and a cause for farm failure. Labor costs for hydroponics are much lower because the produce is the only output of the system. Aquaponics requires growers to manage both fish and bacteria health in addition to produce. Also hydroponics is a much simpler system as nutrients are administered in the exact proportions required. Aquaponics requires more monitoring to ensure the system is functioning correctly and maintain correct nutrient balances. By switching to a hydroponic system Vertigrow was able to cut its labor costs in half (See attached Vertigrow Business Plan).

System Requirements.

Hydroponics is a system, aquaponics is an ecosystem, and as such it requires additional considerations. First it requires 6 weeks of cycling the system to establish the bacteria colonies necessary to support the plants and fish. This delay increases the time it takes for the system to break even and requires additional working capital. It takes at least one year for the system to establish itself and during this period the system is functional but very unstable. During this time additional monitoring will be required to ensure system productivity and prevent a crash. This may translate into additional startup costs if the owner is unable to cover this demand. Additionally aquaponics is more likely to experience a crash than a hydroponic system because there are significantly more failure points, increasing the risk taken on by the owner (See attached Vertigrow Business Plan).

Fish Revenue.

Many additional costs for the system occur because of the additional demands for including fish in the system. However, the fish only contribute a small percentage to the total revenue. A common figure in the literature and online forums is that produce contributes 80% of the systems profitability while fish sales contribute 20%. This may be an inflated estimate as Dr. Nate Story indicated in an interview that in his experience the fish are often a break even proposition at best. In either case fish represent a problem for the commercial viability of aquaponics because it requires a disproportional amount of capital and labor in relation to its economic returns as compared to the produce. Additionally growers may have difficulty finding consumers or contracts for their fish because of the relatively low quantity of production and the fact most growers will not process (clean) the fish on site. This will require markets that will accept whole fish or selling to a middleman which will lower profit margins (See attached Vertigrow Business Plan).

Predictions of Future Growth

Major market penetration by aquaponics is unlikely in the near future. I believe this is largely due to competition from the hydroponic industry. Because aquaponics is based off of hydroponics the systems are capable of growing the same produce with the same fresh, healthy, and organic qualities. Essentially hydroponics and aquaponics are competing for the same market segment. Additionally aquaponic production does not add any inherent value to customers. While its sustainability benefits are well documented and customers are often highly intrigued by the system this does not translate increased demand for aquaponic produce. In an interview, Dr. Nate Storey indicated that his customers appreciated that his system had minimal environmental impact and were fascinated by the interaction of the fish and their produce (N. Storey, Personal communication, October, 2013). However what brought them in was the quality of the produce and the advantage of buying local, which would be the same in a hydroponic system (N. Storey, Personal communication, October, 2013).

The hydroponic industry is highly concentrated with the top two companies (Eurofresh Farms and Village Farms International) controlling 53.4% of the market and the top four companies controlling 59.1% of the market (Kruchkin, 2013). In 2013 the industry grossed $606.8 million in revenue and this is only expected to grow an average 0f 3.63% to 2016 for expected gross revenue of $674.9 million (Kruchkin, 2013). From 2002 industry growth has been highly erratic and averaged 7.14% in annual growth (Kruchkin, 2013). This tepid growth is enough to sustain the industry, but it does not allow room for significant growth in aquaponics. As found with Vertigrow, hydroponics is more economically competitive and will likely outcompete aquaponics for most of the market share. Aquaponics does have the potential to make inroads in small to midsize operations. The increased demand for local food is expected to facilitate growth in small and mid-sized hydroponic operations, so it should be expected to create opportunities for aquaponic growers as well (Kruchkin, 2013). Aquaponic growers will still need to approach their markets creatively as it will face competition from local conventional farms. In the far future water stress may increase the competiveness of both hydroponics and aquaponics as mainstream food production.

Conclusions on Viability

The conclusion of this investigation is that commercial aquaponics can be viable although it is a very high risk venture. Success is dependent on local market conditions and the ability of entrepreneurs to accurately assess market potential in their area and design a system that is appropriate for those conditions. Due to its emphasis on aquaculture and the associated equipment and maintenance costs, the UVI system may not be profitable unless it has a large and accessible market for the fish. In markets where this is not the case the Bright Agrotech model offers a viable approach for entrepreneurs.

Creative approaches such as live produce sales and direct marketing strategies such as running a CSA can help to differentiate growers and overcome the competitiveness in the agricultural sector. As the industry develops creative marketing techniques will continue to emerge that should help aquaponics to exploit niche markets. Aquaponics is unlikely to be a high grossing industry and growers will be attracted to it because they believe in the sustainability benefits of the system or because they greatly enjoy working with the systems. Therefore aquaponics should either be classified as a form of social entrepreneurship or a lifestyle business and it is likely to continue growing in this manner for the foreseeable future. Where profitability is not possible community and nonprofit models may serve to propagate the social and environmental sustainability benefits of aquaponics.

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