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Assisting in the Development of an Aquaponic Greenhouse Enterprise

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ASSISTING IN THE DEVELOPMENT OF AN AQUAPONIC GREENHOUSE ENTERPRISE

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Abstract

The goal of this project was to aid The Worcester Roots Project by advancing the progress of their pilot aquaponic greenhouse, and assist Greenvitalize by exploring options to expand their startup enterprise. To accomplish this goal, our team designed the biological system and assessed the structural integrity of the greenhouse. We also developed a strategic plan for Greenvitalize's enterprise and conducted market analysis of viable species to grown in the greenhouse. This project resulted in a forum that allows Greenvitalize to act as a source of urban farming knowledge and collaboration, and a guide to assist individuals interested in aquaponics to create an enterprise similar to Greenvitalize.

Introduction

A major problem in the U.S. is a lack of access to local fresh foods. Over 23 million people in the U.S. currently reside in food deserts like Worcester. The U.S. Department of Agriculture defines a food desert as a low income area with limited access to transportation that is located more than 1 mile (in urban areas) or more than 10 miles (in rural areas) from a supermarket (Breneman, 2015). Limited access to fresh produce and availability of processed foods has contributed to the nation's obesity epidemic.

Most international produce is either heavily preserved or withered by the time that it reaches Worcester's urban areas. This leaves people living in the urban areas of Worcester unable to get fresh produce at a reasonable price. Currently, organizations in Worcester are attempting to remedy this problem of food insecurity. One such organization is The Worcester Roots Project. Worcester Roots is an organization that works with the community toward social, economic, and environmental justice by aiding in the creation of local co-ops and providing educational programs on the subjects of contaminated soil, development of green jobs, and more. Worcester Roots' commitment to aiding the community, one area that Worcester Roots' focuses on include food justice and food access.

Worcester's abundance of abandoned plots can contribute to a solution to the food desert. According to RealtyTrac data, there are over 400 homes available for purchase in Worcester County that are identified as abandoned (Knothe, 2014). These vacant lots provide an excellent area for building vertical gardens, greenhouses, and other systems to provide fresh produce to the community.

An aquaponics greenhouse can provide local fresh produce. In cold climates food can be grown year round if the aquaponics greenhouse is insulated properly. Urban communities can use vacant as potential plots lots accessible to urban plots and growers. Giving local residents' access to fresh foods leads too much more than improving the health of the community. For example, Growing Power in Milwaukee Wisconsin has been a leader in urban food systems since 1993. Since its inception, Growing Power has offered education programs, created a local source of fresh produce, and served as a center of innovation for its community. Currently, Growing Power has 50 licensed day care gardens created to teach children about urban farming. They also have several urban farming operations throughout Milwaukee. The viability of aquaponics combined with Worcester Roots and their partner, Greenvitalize, provides the opportunity to create a similar operation to Growing Power.

The Worcester Roots Project, along with a network of partners, have built a pilot aquaponic greenhouse in the Main South neighborhood of Worcester. Worcester Roots' immediate goal is to use the aquaponic greenhouse system to lead an open source effort to establish a co-op called Greenvitalize, which will address the health, cultural, and economic needs of the community. This project aims to not only generate jobs and provide access to locally grown fresh produce, but to serve as a model or communities-based greenhouse initiatives. The pilot site consists of a greenhouse structure containing the first prototype of an aquaponic system (Chatani et al, 2015). Greenvitalize is beginning to winterize the greenhouse, populate the system with plants and fish, and develop the business enterprise.

The goal of this project is to assist Worcester Roots and the emerging cooperative Greenvitalize by advancing the development of the pilot aquaponic greenhouse and to help Greenvitalize develop strategic goals, the mission of the aquaponic greenhouse enterprise, and explore strategies for scaling up beyond the pilot site. This will be achieved by:

- Understanding the network of partners
- Improving the physical structure and aquaponic system
- Developing the biological system
- Helping develop the mission and strategic goals of Greenvitalize
- Performing market analysis to determine the species to be grown
- Assessing different ways to scale up the initiative beyond the pilot site.

Background

Overview of Aquaponics

Aquaponics is an integration of aquaculture and hydroponics. The defining feature of an aquaponic system is a soilless system that uses water circulated between plants and fish (Love et. all, 2014). In this manner, waste produced by the fish becomes fertilizer for the plants, thus drastically reducing inputs of nutrients into the system and waste output (Chatani et al, 2015 section i.ii). Fish and other aquatic species excrete ammonia (NH_3) as waste. A portion of this waste ionizes in water to produce ammonium (NH_4). Nitrifying bacteria within the system convert ammonia (NH_3) to nitrite (NO^{2-}) and then to nitrate (NO^{3-}). Plants, which require large amounts of nitrogen to grow, absorb the nitrate from the water (Tyson et al, 2011). This allows for the production of food products from a natural system without the use of environmentally toxic fertilizers.

The Case for Aquaponics in an Urban Setting

The need for a change in our current food system has become evident through its shortcomings. The existence of Food deserts and the necessity of genetic modification of produce are both evidence of an emerging problem in the fundamental culture of food acquisition in America.

Many communities do not have access to fresh produce. The US Department of Agriculture considers an area a “food desert” when low income areas with limited access to transportation are more than 1 mile (in urban areas) or more than 10 miles (in rural areas) from a supermarket. Distances between the farm and the customer can result in quality complications with produce.

Worcester is part of a growing assemblage of food deserts in the U.S. This becomes an epidemic when considering the health implications of this problem. “In general these studies find that better access to a supermarket is associated with a reduced risk of obesity and better access to convenience stores is associated with increased risk of obesity.”(Breneman, *53-54*, 2009). Improving access to fresh produce via community driven farming could enhance the wellbeing of the community. Allowing a community to grow its own food also closes the gap between supply and demand for culturally specific produce. A growing trend to combat to the distance between the source of the produce and where it’s sold has been genetic modification. “Currently, up to 92% of U.S. corn is genetically engineered, as are 94% of soybeans and 94% of cotton (cottonseed oil is often used in food products). It has been estimated that upwards of 75% of processed foods on supermarket shelves – from soda to soup, crackers to condiments – contain genetically engineered ingredients."(About, 2015). Many of these plants are created to increase yield. Some are engineered to resist disease and pests.

The existing methods of agriculture fall short in regard to meeting the demands for a growing population. Agriculture uses pesticides to protect large fields from parasites, neglecting to account for the effects these chemicals have on the cultivators and ecosystem. A study in India showed that workers exposed to pesticides showed more health complications than those in other occupations: "When queried about symptoms of peripheral sensory neuropathy in the form of tingling sensation, burning/pricking pain in hands or feet, 40% of the pesticide sprayers and 9.1% of persons engaged in other occupations, had these complaints." (Mathew, 2015). Four common pesticides in use today are also known to have a toxic effect on the larvae of the honey bee (Zhu, 2015). This can have devastating effects on the ecosystem. Aquaponics does not require pesticides because it grows produce in a closed system with a limited exposure to open air. Instead, aquaponic greenhouses can use pest control systems to distinguish between insects that are harmful to the crops and those that help the crops (Greer, 1999). By integrating fish farming with crop production, the problem of fish farming's environmental toxicity is reduced. "Fish-farming contributing to marine waters eutrophication, feces and uneaten food pellets from fish farms alter the organic matter in the sediment, which can change the consumption of oxygen and cause local eutrophication."(Mancuso, p.88)

The advantage of using aquaponics as an urban farming supplement to the food system is the flexibility and efficiency of this type of farming. A comparison can be made by food output per area used: "Another way of looking at it is that over the course of a year, aquaponics will generate about 35,000 pounds of edible flesh per acre, while the grass-fed beef will generate about 75 pounds in the same space."(Bernstein, 2011).

Further advantages of aquaponics area utilization include the ability to house these systems in smaller spaces. Agriculture requires acres of open field while aquaponics systems can be set up inside of closed spaces such as abandoned buildings or warehouses (Bernstein, 2011). Another consideration is the use of resources. In America, we have developed a food system in which food is generated far from demand. This way of living uses more resources than necessary and alienates us from our food source. The environment benefits from fuel saved by growing food closer to the consumers. "-Hong Kong and Singapore already both produce more than 20 percent of their meat and vegetables within the city limits."(Bernstein, 2011). Using aquaponic greenhouses is just one way to accomplish this.

Emerging Urban Food System in Worcester

There are sections of the Worcester community that can only access fresh produce if they have a car that can drive them to the nearest store (as shown in Fig. 2). Not having fresh produce within walking distance or near a local bus route severely limits the ability for the community to access fresh food.

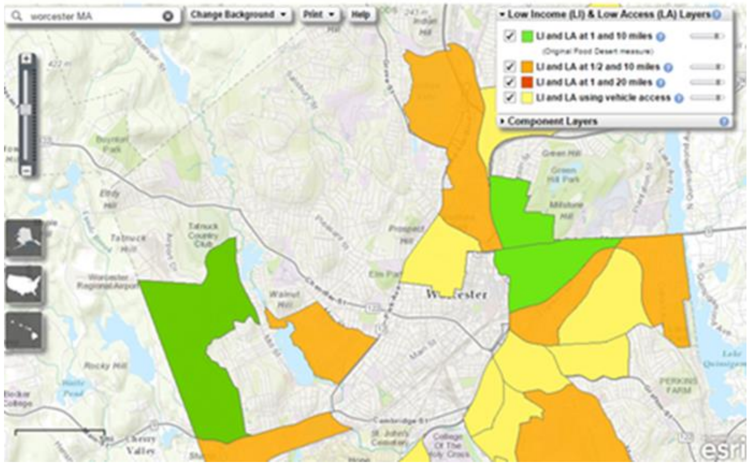

FIGURE 1 DIAGRAM OF FOOD DESERTS IN WORCESTER USING INFORMATION FROM A RECENT INTERNATIONAL CENSUS. UPDATED MARCH, 2015 (BRENEMAN, 2015)

Because of the food desert present in Worcester, many organizations have been created to combat the dwindling access to fresh produce. Community Supported Agriculture (CSA) is a program that pays a farm in advance for a share of the produce. Some CSA programs even allow for a flexible monthly payment plan (Lebeaux, 2015). Nuestro Huerto is a community farm that donates some crops to local businesses while also connecting the community to their food source. (Solin, 2015). Stone Soup Community Center provides the community with social, environmental, and economic justice through many programs including the greenhouse initiative that our team is assisting in. (Stone, 2015) The Regional Environmental Council (REC) also focuses on action to support environmental, social, and economic justice (What, 2015).

The Worcester Roots Projects is a community driven organization focusing on economic, social, and environmental justice. They aim to support the struggle of the common person to live a healthy life in a non-toxic environment. Currently Worcester Roots has invested in efforts to create an aquaponic greenhouse that runs on a co-operative business model. Stone Soup Kitchen has partnered with Worcester Roots to ensure the community and surrounding neighborhood of Main South benefit from the aquaponic greenhouse as well. Maine South is a key focus for this project because it is designated as a food desert in figure 1, and is also designated as an environmental justice focus area. Greenvitalize is another cooperative greenhouse enterprise taking initiative in the project led by Howard Lucas.

FIGURE 2 WORCESTER ROOTS GREENHOUSE AT STONE SOUP COMMUNITY CENTER

Aquaponic Greenhouse Design

The defining feature of an aquaponic system is a soilless system using water circulated between plants and fish (Love et all, 2014). Previously there was a team at WPI focused on the development of the structure and biological system of the aquaponic greenhouse. In this section, we will discuss both the decisions the previous team made regarding the design of the aquaponic system at Stone Soup Community Center and decisions yet to be made.

Aquaponic System Structure

Type	Media Filled Grow Bed	Nutrient Film Technique	Deep Water Culture (floating raft method)
Pros	Easy for beginners due to lack of filter Flexible choice of size and shapes	No special grow medium required Easy to adapt from other existing structures	Best for commercial application because of high output Can be automated
Cons	Less harvest crops than other techniques	Limited to small root systems	Requires special filters to avoid root rot

TABLE 1 TYPES OF AQUAPONIC SYSTEMS

Species Requirements

Species	Temperature (C)		Total ammonia nitrogen (mg/liter)	Nitrite (mg/liter)	Dissolved Oxygen (mg/liter)	Crude protein in feed (%)	Growth-rate (Grow-out stage)
	Vital	Optimal					
Common carp	4-34	25-30	<1	<1	>4	30-38	600 grams in 9-11 months
Nile tilapia	14-36	27-30	<2	<1	>4	28-32	600 grams in 6-8 months
Channel catfish	5-34	24-30	<1	<1	>3	25-36	400 grams in 9-10 months
Rainbow trout	10-18	14-16	<0.5	<0.3	>6	42	1000 grams in 14-16 months
Flat head mullet	8-32	20-27	<1	<1	>4	30-34	750 grams in 9-11

							months
Giant river prawn	17-34	26-32	<0.5	<2	>3	35	30 grams in 4-5 months
Barramundi	18-34	26-29	<1	<1	>4	38-45	400 grams in 9-10 months

TABLE 2 SPECIES REQUIREMENTS, ADAPTED FROM TABLE 7.1 (SOMMERVILLE, 2014)

Policies and Funding Considerations

Because the issue of food deserts and urban food systems lacking fresh sources of produce is a national problem, there are grants that are available to help establish startup funds for urban farming enterprises. The United States Department of Agriculture (USDA) provides several food programs for low income families and people over the age of 60. These programs aim to provide a nutritious diet for people who traditionally may lack access to a proper healthy diet. The USDA also created the Competitive Grants Program, which awards 8.64 million to allow people to create community food projects, planning projects, training, and technical assistance. Aquaponic greenhouse programs can fall under all of these sections depending on its stage of development. Worcester currently has limited existing regulations for aquaponics greenhouses. However, Boston uses Article 89 to properly regulate 37 different urban farming initiatives, including aquaponic greenhouses. Article 89 defines aquaponics as a "means the cultivation of fish and plants together in a constructed, recirculating system utilizing natural bacterial cycles to convert fish wastes to plant nutrients, for distribution to retailers, restaurants and consumers." (Article 89)

Methodology

The goal of this project was to aid The Worcester Roots Project by advancing the progress of their pilot aquaponic greenhouse, and assist Greenvitalize by exploring options to expand their startup enterprise.

Objectives Overview

1. Understand network of partners involved with the Worcester food system
2. Improve the physical structure and aquaponic system
3. Develop the biological system
4. Help develop the mission and strategic goals of GreenVitalize
5. Perform market analysis to inform the selection of species to be grown in the greenhouse
6. Scale the greenhouse initiative beyond the pilot site

Understanding the Network of Partners Involved with the Worcester Food System

The first step we took to explore scaling up the aquaponic greenhouse initiative at Worcester Roots was to understand important actors in the sustainable food network in the greater Worcester area. We met with many important actors and organizations involved in the sustainable food network of the Worcester area to gain insight on these topics. These meeting included the members of Worcester Roots themselves and Howard Lucas, the head of GreenVitalize. We also met with Jenny Isler (part of the Real Food Challenge at Clark University) and Dr. Ramon Borgez-Mendez (who teaches at Clark University with a PhD in community organizing). We also contacted and interviewed Dave Barr (a manager of a nearby aquaponic farm in Rehoboth, Massachusetts), the Worcester Regional Chamber of Commerce, and the Regional Environmental Council.

Our meetings with Barr Family Farms in Rehoboth, Massachusetts (Mr. Dave Barr) was vital to learn about the techniques and equipment that are used for maintaining an aquaponic system in real-world conditions. We also introduced ourselves and the project to the Regional Environmental Council, a key organization in the local sustainable food community that is invaluable for finding groups for future collaboration. Conducting interviews with Jenny Isler and Dr. Ramon Borgez-Mendez also gave us valuable information about organizing and supervising urban farming and food security programs in the Worcester area. Lastly, our meeting with Karen Pelletier (the “Director of Higher Education- Business Partnerships”) and Stuart Loosemore (the “General Counsel and Director of Government Affairs and Public Policy”) at the Worcester Chamber of Commerce gave us valuable insights into local food production, including restaurants that are a useful source of information and may prove to be a profitable market in the future.

Improve the Physical Greenhouse Structure

The Aquaponic Greenhouse located at Stone Soup kitchen is fully assembled but not completely operational. We analyzed the current state of the greenhouse by monitoring the heat loss via instillation of a temperature and humidity sensor. It is essential for an aquaponic greenhouse to be able to maintain a stable temperature and humidity level during all seasons; otherwise the species in the system will be affected negatively. The data from the temperature and humidity sensor allowed us to determine if the greenhouse needs more insulation. We have also helped repair parts of the aquaponic greenhouse that had broken by assisting with the replacement of the insulation. This was necessary because some of the insulation had cracked due the frigid temperature this past winter.

Develop the Biological System

In order to test the feasibility of the current greenhouse system at Worcester Roots, we determined what species of plants, fish, and growing medium establish a healthy bacterial ecosystem. We made these choices based on which species have the least required maintenance and the highest chance of survival. We also researched extensively This knowledge was gained from our meeting with Dave Barr from Barr Family Farms as well as extensive review of published literature and case studies. We then presented to Worcester Roots a list of species and growing materials that they need in order to create and maintain the simplest aquaponic system possible.

Help Develop the Mission and Strategic Goals of GreenVitalize

The Worcester Roots staff collective has successfully identified a partner who will lead the greenhouse cooperative initiative. That partner is GreenVitalize, an emerging co-op that was started by Howard Lucas. Howard Lucas is a visionary whose goal is to reform the state of the Worcester food system into a self-sustaining community based program. Using the greenhouse as a pilot site, it is important to set goals that will bring Greenvitalize from a small scale facility to a large scale contributor to the Worcester food system. Working toward the educational endeavor, we spoke to Mark Berthiaume (communication and school support coordinator for Worcester Public Schools) to determine if there is potential for the aquaponic greenhouse to provide an educational benefit to the community. We also spoke to teachers at Forest Grove Middle School to discuss the potential for the aquaponic greenhouse to be integrated into the school's STEM curriculum.

In the interviews with the Worcester Regional Chamber of Commerce and the Regional Environmental Council, we discussed where the produce from the aquaponic greenhouse is best placed. We discussed the potential to sell to local businesses that purchase from local suppliers as well as the potential to contribute to various urban farming initiatives. We also met with Jenny Isler from Clark University who oversees a freight farm on that campus. We discussed with her the potential for Greenvitalize to provide food to a college campus as well as other programs such as training programs and tours of the aquaponic greenhouse.

Perform Market Analysis to Inform the Selection of Species to be Grown in the Greenhouse

Another important objective of this project is to perform market analysis to determine what species would be most socially and economically profitable to grow in the aquaponic greenhouse. This is an important decision to make because when the greenhouse initiative has spread beyond the pilot site, it will be important to create revenue for the workers of the co-op. We contacted restaurants and spoke to various organizations in Worcester in order to determine what species of plants and fish should be grown in the aquaponic greenhouse to create economic revenue. We interviewed managers of restaurants including Volturno Pizza, EVO, and Flying Rhino to ask them about their local produce purchasing. From the REC, Worcester Regional Chamber of Commerce, and Jenny Isler at Clark University, we explored the viability of different institutions in Worcester as markets, including universities, nursing homes, and colleges. We asked what produce these urban farming initiatives currently provide to institutions, where they locally distribute their produce, and how they transport and distribute their produce.

Scale the Greenhouse Initiative Beyond the Pilot Site

One possibility of scaling up the aquaponic greenhouse is the implementation of many modular structures located close to the demand which they are meeting. Another possibility is the construction of one larger factory-style aquaponic greenhouse that will utilize its size to meet the demand of the many locations within a distribution radius. To gain a better understanding of the effects and inner workings of providing to a large institution, we met with Jenny Isler from the Clark University Real Food Challenge Initiative and discussed possibilities for scaling up to go beyond the pilot site. We also inquired about possibilities for funding an initiative such as this. From our sources we were able to determine the most feasible and beneficial business model that the greenhouse could conform to.

Findings

The Network of Partnerships Involved with the Worcester Food System

Understanding important actors of the sustainable food network in the greater Worcester area, (including understanding key stakeholders in the greenhouse initiative at Worcester Roots as well as other actors in the broader sustainable food network in and around the city of Worcester) is important to keeping the project productive and an asset to the community. To this end, we have met with a number of people. These meetings and interviews have proven a priceless source of information and allies. **The table in Appendix E summarizes our interviews, giving the name of the person contacted, their organization, and a short description of what we discussed.**

Improving the Physical System

The aquaponic greenhouse was assembled October 2015. Upon inspection of the final assembly, our team noticed a few structural flaws in the greenhouse, including cracks and gaps in the physical structure and poor use of internal space in the greenhouse. After frigid temperatures this winter, the wooden structure has warped. This caused the caulking between seams of the structure to break, leaving small gaps. These gaps between the wooden structure and the window panes allowed heat to escape, causing the temperature in greenhouse to fluctuate. Drastic fluctuations can send the fish into shock and kill plants (see Appendix A). We worked with The Worcester Roots Project to fix most of the flaws, however **some gaps in the upper windows of the structure still remain.** These will need to be filled. Additionally, **a method of limiting the temperature in the greenhouse will be needed**, possibly through the use of vents and fans, as temperatures were shown to reach a high of 129 degrees Fahrenheit.

Developing the Biological System

Currently the aquaponic Greenhouse is not fully operational. A key task in progressing the aquaponic project has been developing a biological system. Our team has determined the major components of the biological system and appropriate steps for initiating that system.

The first step is to **fill the grow bed and fish tank.** Once the water has settled for more than 24 hours, our team must **test the quality of the water** to identify any contaminants that may affect the health of the fish, crops, and any consumers of the crops harvested. After testing, steps must be taken to correct or remove any contaminants. The water must also be aerated to ensure proper dissolved oxygen content (vital for fish health - see Appendix A). **Only after ensuring water quality can fish and plants can be added to the system.**

Pea gravel was chosen as the growing medium because of its price. This medium is much less expensive than other alternatives. Before introducing the gravel to the system, it must be tested for concentration of limestone (limestone can increase the pH and acidity of the water, killing fish and plants- see Appendix A for more information). A simple test for the presence of limestone involves pouring a small amount of vinegar over a sample of the gravel and looking for bubbles. If the gravel bubbles, limestone is present. If limestone is found within the pea gravel, steps will need to be taken to remedy the situation (using a different medium, finding a different source of gravel, or using aquarium treatment chemicals to balance the pH).

Microgreens were selected as the optimal starter crop based on the viable market (shown by our market research) and ease of cultivation in this system. Small roots and plants mean less space is needed, and thin, small leaves mean less water is absorbed (compared to fruits such as tomatoes). These greens also grow fast, meaning more harvests.

Tilapia was selected as the starting aquatic crop because this species does not cannibalize, matures quicker, reproduces with less maintenance than other options, and is incredibly resilient, allowing them to survive in a large range of temperatures and pH levels. Other options were rejected because of their difficulty in keeping (being sensitive to water quality or temperature, having difficult reproduction processes, or being too aggressive), or because they were unlikely to find a market (too difficult or unpleasant to consume). See Table 2 for more information on fish selection.

Research proved that **juvenile fish are the best age group to introduce into the fish tank** because of ease of acclimatization. While the current tanks can support 15 fully grown red Nile tilapia, introducing fish in small amounts (5 fish) is often recommended to allow them to become acclimated to the new environment. Once the first set of fish have become acclimated, additional fish can be added to the tank. However, any fish to be added after the initial group must be kept in quarantine in an isolation tank to ensure diseases or parasites from the new set does not infect the existing tilapia. It is also important to note that snails and goldfish can carry parasites that infect tilapia: never introduce goldfish into an aquaponic system containing tilapia, and take care to prevent a snail infestation.

Strategic Goals or the Greenvitalize Cooperative Enterprise

It's clear from literature, research, and the interviews that the viability of supporting the enterprise from market sales is not realistic at this time since the current scale of **the aquaponic greenhouse cannot create enough produce for an anchor institution**. Therefore, a key strategic goal for Greenvitalize in the next few years will be to obtain grants from the government to sustain the co-op and expand the enterprise. Partnering with schools (and/or the Worcester Environmental Council) for the purpose of creating an educational program creates the ability for Worcester Roots to apply for educational grants. These grants are available through the EPA and NSF (such as the EPA Environmental Education Grant) and will provide much needed funding for the program in its infancy.

After speaking to Mark Berthiaume, we learned that there is some interest for incorporating agricultural sustainability into the curriculum of Worcester Public Schools. In addition, since the Worcester Public School system's food comes from an independent food service, they may be easier to work with than larger food distribution companies. Therefore, **the Worcester Public School system may prove a valuable transitional tool**, giving Greenvitalize an easy transition from providing mostly education programs to providing education and produce to the local schools (once production is up to scale). We believe that this will be an effective way to orient Greenvitalize's enterprise as it grows, since this will address the educational (and eventually nutritional) needs of the community while spreading interest for the entire urban farming initiative and qualifying the program as a possible recipient of educational grants.

Though there is a viable market in selling produce to restaurants, this is possible only at a larger rate of production than the greenhouse is currently able to sustain. An educational program is a better candidate for an initial activity because an aquaponic system of this scale can have an entire hands on curriculum based around it for students, providing greater good to the community than mere food distribution can provide. **Donating the small amounts of produce grown in the greenhouse to local food charities is another possible way to raise awareness of the co-op and lead to future partnerships.**

Market Analysis of Species Able to be Grown in an Aquaponic System

The market for local produce in Worcester consists of many small corner stores, ethnic markets, local restaurants, and institutions. In our interview with John Amador, we discussed the system through which local businesses get their locally sourced produce. This system consists of a purveyor, or middle man, that collects the produce from the farmers. **Greenvitalize would need to partner with these purveyors in order to get produce to the markets**. Through this interview it became evident that the success of a local producer depends on their choice of crops. Greenvitalize would need to tailor their crops to meet the needs of the local purveyor and the community at large. Through other interviews with leaders of institutional food programs and inquiring at local restaurants, we have gained an understanding of what produce would be valuable to the community market.

We have found that **restaurants have the highest demand for microgreens.** Microgreens have a high selling point because they are difficult to transport while maintaining their quality. This is ideal for a locally produced crop since transportation will be minimal. Market viability of the fish crop was found to be low. We have found that it is more important to pick a durable fish that won't require a lot of maintenance and can consistently provide nutrients to the plants. Tilapia remains the best choice under these goals. Since tilapia are also an easily viable crop for large scale fish farms. **It is unlikely that the fish produced from this system can be sold for a significant profit.** However, the lack of significant transportation costs may allow for the sale of tilapia at a small profit once the scale of the operation increases.

Scale the Greenhouse Initiative Beyond the Pilot Site

After Greenvitalize has gained more support, and the pilot aquaponic greenhouse has proven capable of production, the next step will be to go beyond the pilot site and begin to scale up the program to have a greater impact on the Worcester food system. Having a larger impact on the Worcester food system (and promoting Worcester food justice) requires an expansion from the Stone Soup Community Center pilot site.

We have investigated two possible avenues of expansion. The first is *multiple modular systems:* many aquaponic greenhouse systems throughout Worcester, based closer to the demand for the food it is producing. This requires a modular structure that can be implemented in a variety of locations; making management of the operation more difficult, but also lowering transportation costs. The second option is a *single larger system*; locating a larger plot of space that can house a greater number of food producing beds. This will entail larger transportation costs, but make larger harvests easier to produce. After discussing the benefits and drawbacks of each, **Greenvitalize has chosen the multiple modular systems solution**.

Growing the enterprise beyond the pilot site may prove challenging because of the many regulatory issues that are involved in both scaling up an aquaponic greenhouse as well as providing food for public consumption. After speaking with the Regional Chamber of Commerce, we found that **any form of farming for food production in Worcester is technically illegal.** This is an important matter to consider and may need further exploration. However, the WRCC also informed us that the city is working on a possible revision of these zoning laws in the near future. Another regulatory issue to be considered was mentioned by Dr. Borges-Mendez. He informed us that t**he FDA must be involved with all productions of meat for consumption.** This would add considerable hurdles to any scaling effort. He asserted that **regulations for producing plants are much less stringent**, potentially pointing to a focus on produce as a more viable goal.

Key Findings

- See Appendix E for interviews with key contacts in the Worcester Food System
- The pilot site is not yet finished:
    - Some gaps in the insulation at the pilot site need to be filled
    - The pilot greenhouse needs ventilation. Currently the temperature rises too high to support a healthy system.
    - Water needs to be added to the pilot system. Water must be tested and conditioned to ensure quality.
    - Pea gravel was found to be the optimal medium. This gravel must be tested for limestone before being used.
- Crops were chosen:
    - Microgreens were found to be the optimal starting crop, both in ease of cultivation and in viable market.
    - Tilapia was found to be the optimal starting aquatic crop. Use a small (>=5) group of juvenile fish for introduction to the system.
- The pilot greenhouse in its current state cannot produce enough for sales to fund its function.
    - Focus on educational programs and apply for governmental grants instead.
    - Donating the produce until the system is producing enough to sell is a valuable way to raise awareness.
    - The Worcester Public School system may provide a valuable transitional tool to take the project from a solely educational focus to also producing produce for an anchor institution.
    - It is unlikely the fish produced from this system can be sold for a significant profit, and regulations surrounding the sale of meat may prove to be prohibitive. However, regulations for production and sale of produce are much less stringent.
- To sell to restaurants, the project must partner with a local produce purveyor.
- A possible issue of concern is that urban farming in Worcester is not yet legal, though it may become so soon.
- The multiple modular system solution was chosen as a plan for future growth.

Accomplishments and Deliverables

Working closely with Worcester Roots and Greenvitalize, we have produced three major accomplishments. Our team helped advance the progress of the aquaponic greenhouse at Worcester Roots through assessing the status of the physical structure and advancing the development of the biological system. We were able to assist Greenvitalize by creating a forum for their website which will help the urban growers' community to collaborate on methods of farming and coordinate efforts to assist each other. Lastly, we have created a guide to assist individuals that want to create an aquaponic greenhouse enterprise similar to the enterprise that Greenvitalize has planned for the aquaponic greenhouse at Worcester Roots. These accomplishments and deliverables have helped to aid Greenvitalize and Worcester Roots expand the greenhouse initiative by encouraging the planning of other aquaponic greenhouses to be built. Thus contributing to Greenvitalize's and Worcester Roots' positive impact on the Worcester food system.

Advancing the Pilot Aquaponic Greenhouse

The greenhouse at Worcester Roots is not yet running. At the beginning of this project the greenhouse contained the basic architecture of an aquaponic system, but nothing more. We assisted Worcester Roots by researching various different growing mediums, water flow techniques, and species in order to provide them with a system and species that would be easy to grow and maintain in the greenhouse in order to help gauge the stability of the aquaponic greenhouse. We helped to fill the grow beds with the grow medium that was recommended. In addition to providing Worcester Roots with recommendations, we also assessed the current state of the greenhouse structure.

A temperature and humidity sensor was installed in the greenhouse to determine if the conditions in the greenhouse are suitable for growing. Beginning February 2nd, the temperature and humidity sensor took a measurement every half hour until April 15th. This data helped to gauge the greenhouse's resilience to fluctuations in temperature. Shown below is an example of one day's worth of temperature readings, from midnight to midnight. The temperature is highest early afternoon.

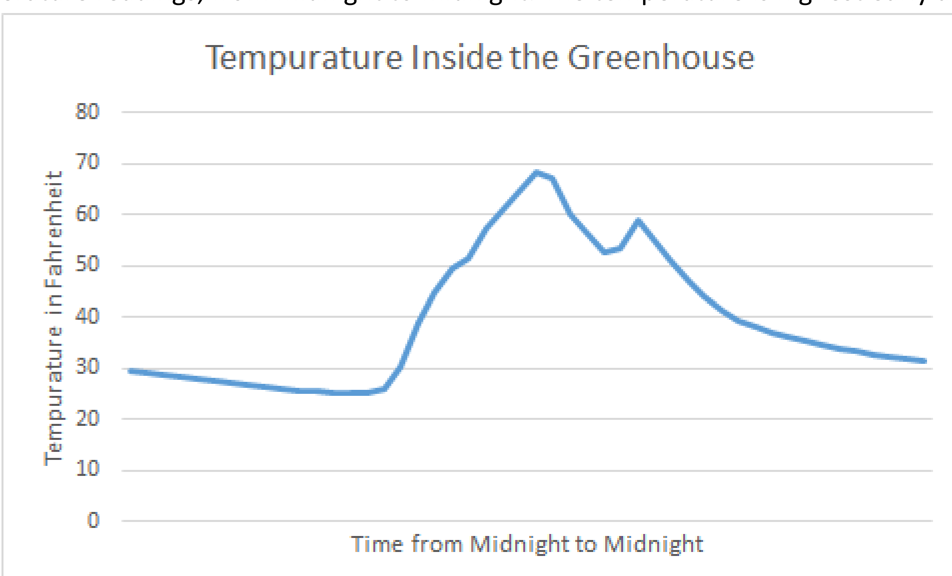

FIGURE 2 TEMPERATURE GRAPH

A smoke bomb test was done to determine if there were any leaks in the aquaponic greenhouse and we found that panels on the roof of the greenhouse are not sealed well and let air escape easily. Below is an image of a panel that is leaking. Fixing these will help insulate the greenhouse.

FIGURE 3 LEAK IN THE GREENHOUSE ROOF

This information helped Worcester roots by directing their attention to key flaws in the structure of the greenhouse. These assessments have brought Worcester roots closer to a functional system.

Creation of a Forum for Urban Agriculture Discussion

In addition to assessing the physical structure of the aquaponic greenhouse, we assisted Greenvitalize by creating a forum for their website. This forum was created to provide anybody interested in urban farming and food justice with a place to discuss issues faced by the community and to compare urban farming techniques. The forum includes sections on aquaponics, vertical farms, hydroponics, and aeroponics to allow people to discuss the technical aspects of their setups and to ask the community for recommendations and suggestions. The forum also includes sections on legal issues faced by urban farmers such as the legality of certain species of plants and animals as well as regulations like zoning laws. Lastly, the forum has a section for individuals to inquire about Greenvitalize and offer their support or request that Greenvitalize take interest in their projects. The forum will help to unite all urban farmers by giving them an area to congregate, discuss ideas, and promote interest in food justice. Below is the overview page of the forum, as shown, many different topics are available for discussion.

Forum	Topics	Posts	Freshness
GREENVITALIZE URBAN GROWERS Business Structure (0, 0), Community Outreach (0, 0)	0	0	No Topics
Urban Agriculture Financial Topics (0, 0), Food Deserts (0, 0), Food Security (0, 0), Legal Topics (0, 0), Local Food Systems (0, 0)	0	0	No Topics
Aquaponics Electrical Topics (0, 0), Fish Topics (0, 0), Flow System Topics (0, 0), Material Topics (0, 0), Physical Structure Topics (0, 0), Plant Topics (0, 0)	0	0	No Topics
Aeroponics Electrical Topics (0, 0), Flow System Topics (0, 0), Nutrient Topics (0, 0), Physical Structure Topics (0, 0), Plant Topics (0, 0)	0	0	No Topics
Vertical Farming Electrical Topics (0, 0), Flow System Topics (0, 0), Material Topics (0, 0), Physical Structure Topics (0, 0), Plant Topics (0, 0)	0	0	No Topics
Miscellaneous	0	0	No Topics

FIGURE 4 FORUM FRONT PAGE

Creation of a Guide for the Creation of an Aquaponic Greenhouse Enterprise

Another accomplishment was the creation of a guide "Creating an Aquaponic Greenhouse Enterprise". This guide was created with the goal of helping anybody who is interested in creating an aquaponic greenhouse with the process of deciding what kind of structure they want to build and what goals they choose for their endeavor. The guide takes the reader through the process of making connections within the community and gives the reader advice on how to form valuable partnerships. The guide also helps the reader choose what kind of market they want to be a part of. Providing the guide to Worcester Roots and Greenvitalize makes it easier for them to involve other people in the project and point people with similar interests in the right direction. Below is a section from our guide, the entirety of the guide can be found in Appendix G.

How Aquaponics Works

Aquaponics is a type of farming that uses fish to create fertilizer for plants. Aquaponics works by mimicking the natural cooperation of an ecosystem. Fish produce waste that contain ammonia, which is toxic to the fish. In an aquaponic system, ammonia filled water from a fish tank is fed to plants where billions of bacteria in the growing medium break the ammonia down into nitrate. Plants use nitrates as a fertilizer and remove it from the water with their roots. This cleans the water for the fish. This natural and sustainable process produces high quality food without the need for fertilizer and drastically reduces waste.

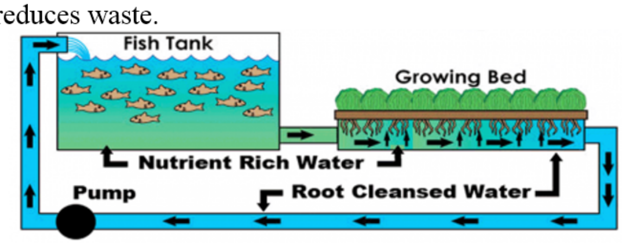

FIGURE 5 SECTION FROM THE GUIDE

Lastly, through all of our interviews with organizations and experts within the Worcester community we were able to introduce Greenvitalize to the community in a way that will garner partnerships in the future. During our interviews we discussed the goals of Greenvitalize and the potential for Greenvitalize to assist in the repairing of the Worcester food system.

Recommendations

Considering the future development of the aquaponic greenhouse, there are many steps that remain to be taken in order to turn the aquaponic greenhouse at Worcester Roots into a fully operational enterprise that combats the food desert of Worcester. These steps are composed of continued communication within the Worcester food justice community, continued development of the pilot aquaponic greenhouse, short term milestones for Greenvitalize, and long term milestones for Greenvitalize. We believe that if these steps are taken by Worcester Roots, Greenvitalize, and future students enrolled in similar projects, Greenvitalize can become a major player in promoting food justice in Worcester.

Immediate Community Outreach Recommendations

We recommend that Greenvitalize continue to speak with prominent organizations in the community. By continuing to set up meetings, and discuss the potential impact that the aquaponic greenhouse enterprise could have on the community, Greenvitalize will continue to gain support from the community and increase in scale. Below is a table of community organizations that have not yet been contacted. They are potential resources and will help direct the members of Greenvitalize toward the most impactful enterprise possible.

Acentria	A community farm to teach farming skills to older adults, individuals with disabilities, teens, young families, and refugees
Community Harvest	A501(c)3 nonprofit that runs a volunteer-staffed farm tasked with producing fresh fruits and vegetables for the various shelters, soup kitchens, and food banks here in Worcester County
Nuestro Huerto	CSA farm that is part of Worcester Roots. Focuses on providing the community with access to fresh produce and a means of connection. Donates some crop to local business.
Lettuce be Local	Farm-to-table food distributer. Mentioned by Worcester Chamber of Commerce as potential contact.
Farm Fresh RI	Farm-to-table food distributer. Mentioned by Worcester Chamber of Commerce as potential contact.
Evoo	Local restaurant. Mentioned by Worcester Chamber of Commerce as potential contact.
Designing a Bioshelter in Worcester	IQP aimed at creating a year-round self sustainable urban food production system.
Worcester Food & Active Living Policy Council	Group aimed at food justice.

TABLE 3 LIST OF ORGANIZATIONS TO BE CONTACTED

In addition to contacting these organizations, we recommend continuing to communicate with organizations that have already been contacted such as the REC and WRCC. Continuing to update these two organizations on the progress of the pilot site will create opportunities for Greenvitalize to partner with these organizations for obtaining grants and directing the species grown in the aquaponic greenhouse towards positively impacting the community.

Immediate Aquaponic Greenhouse Recommendations

In order to further the progress of the greenhouse development we recommend that the pump and syphon system be stress tested in order to assess its viability in its current state. The continuous functionality of the pump is essential to a functional aquaponic system. Currently there is a pump installed but it has not been tested. Testing the pump as soon as possible will help determine how much water flow is to be expected from the current system.

Additionally we recommend that the panels on the roof of the greenhouse that we determined were leaking be resealed. We found that some sections were simply missing insulating foam. Filling the gaps in the panels with insulating foam and sealing them with caulk should effectively insulate the greenhouse and prevent the extreme temperature fluctuations that currently happen in the greenhouse. In addition, the door is currently broken, which is also causing leaks and temperature fluctuations. Repairing and insulating the door, specifically to prevent air from entering and exiting from underneath the door, will help to stabilize the temperature in the greenhouse.

Short Term Goals

To progress the interests of Greenvitalize, we recommend the following goals be accomplished within the next six months as they are eminently achievable and will accelerate the processes of scaling up. Firstly, after the current system is tested, a second system should be constructed that is identical to the first system. This system should be built on the opposite side of the greenhouse because currently, the aquaponic system in the greenhouse takes up less than half of the space available. After these two systems have been constructed, tilapia and lettuce seedlings should be purchased and placed into the aquaponic system. We have selected these species because they are the easiest species to grow and maintain and these species are also the most resilient to unstable environments. These factors will allow for Greenvitalize to grow crops in the aquaponic system without mistakenly ruining the entire harvest due to miscalculations. The forgiving nature of these species makes them an excellent first choice for the aquaponic system. It is essential to begin testing the aquaponic systems as soon as they are built in order to measure the growing power of the greenhouse before attempting to establish partnerships so that Greenvitalize is aware of the output potential of the aquaponic greenhouse.

In six months, once the aquaponic greenhouse is fully operational, we recommend that Greenvitalize begin by donating the produce grown in the aquaponic greenhouse to the Worcester County Food Bank and Rachel's Table, a soup kitchen. This will create awareness of Greenvitalize and prove to the community that they are interested in helping. During this donation period, Greenvitalize should hold meetings with the schools in the area to discuss the potential for the aquaponic greenhouse to be integrated into the student's curriculum. We recommend that this aquaponic greenhouse's purpose be entirely educational because it is too small to produce enough food for a store or restaurant to take interest. Educational programs will encourage youth to take interest in Greenvitalize's aquaponic greenhouse enterprise which will help to spread Greenvitalize's influence over the community. The educational benefits of the pilot site are not only for the community. The pilot site should also be used to experiment with different types of aquaponic systems so that those who are interested in aquaponics can learn about new techniques.

Long Term Goals

Long term, we encourage Greenvitalize to continue to pursue educational partnerships and perhaps move on to contracts with larger institutions. In a year, we recommend that Greenvitalize have a working contract with a school to provide educational programs and field trips to the students. After Greenvitalize has a stable relationship with a school, it should look to expand to other sites. By this we mean look for other places and organizations that also want to build an aquaponic greenhouse. Building multiple greenhouses will increase the amount of produce available for sale without requiring permits that one large facility would require. In two to three years, Greenvitalize will hopefully be overseeing multiple aquaponic greenhouses build by schools and small organizations that Greenvitalize oversees. At this point we recommend that Greenvitalize begin to speak with local restaurants and corner stores and agree to supply one or two with microgreens, as they are one of the most desirable and valuable crops able to be grown in an aquaponic greenhouse. These first contracts with sellers of local produce will help Greenvitalize establish itself in the local food market. This publicity and revenue will help to build and finance even more small aquaponic greenhouses throughout the city. As Greenvitalize continues to grow in size, it can begin to look for larger institutions to partner with.

In five years, we recommend that Greenvitalize partner with an anchor institution. Anchor institutions require a lot of produce so Greenvitalize should start exploring this opportunity in the near term. That way they can plan accordingly and develop their goals around meeting anchor institution needs. Greenvitalize should look to supply the anchor institution with one key ingredient of their meals, such as lettuce, tomatoes, or kale. With two dozen aquaponic greenhouses of a similar size to the current one, we believe Greenvitalize will be capable of supplying an anchor institution with produce. This will be a tremendous achievement and will help to make a major impact on the Worcester Food System.

Aquaponic Greenhouse Business Models for Scaling Up

An essential part of creating a business is relating the investors to the social, economic, and cultural revenue. If this system is not in place, then finding people or organizations to invest in Greenvitalize (the co-op running this aquaponic greenhouse) is very difficult. A cooperative is a system where a group of initial investors all contribute equally at the start of a business. When a decision regarding the business has to be made, all the investors have an equal vote in the decision. Cooperatives are usually non-profit organizations, but when the business creates excess revenue it is shared among all the investors equally (Fernandez, 2010).

Another option for a business model is the community owned corporation. A community owned corporation is similar to a standard for-profit business structure, but with emphasis on the community. A community owned corporation has shares in the business purchasable by anyone. The decision making process for a community owned corporation gives investors a say in the decisions proportionate to the number of shares they own.

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Appendix A: Additional Biological System Research

Successful aquaponics involves the careful balance of nutrients and pH for the optimal growth of plants, fish and nitrifying bacteria (Tyson, 2007). In particular focus is finding a balance between water pH optimal for nitrification (a pH of 8.5) and plant growth (a pH of 6.5). A higher pH (at 8.5) both encourages ammonia(NH_3) oxidation (NH_4+ conversion into NO^{2-} by ammonia-oxidizing bacteria -e.g., Nitrosomonas Europaea or Nitrosococcus Oceani (Butler et al) (1.75 times faster at a pH of 8.5 vs a pH of 6.5) (Tyson, 2007) as well as nitrite oxidation (NO^{2-} conversion into NO^{3-} by nitrite-oxidizing bacteria - e.g., Nitrobacter Winogradsky (Knanal)) (1.3 times faster at a pH of 8.5 vs a pH of 6.5) (Tyson, 2007). This increase in efficiency of nitrification would allow more fish to be kept in less water as well as speed plant growth by increasing nutrient availability (Tyson et al, 2011). However, the greater increase in ammonia oxidation compared to nitrate oxidation results in a buildup of nitrite, which, if left unchecked, would reach levels toxic to plants and fish. A higher pH also results in higher percentages of unionized ammonia (Knanal) - a form that is both toxic to fish and also lowers plant nutrient uptake (Tyson, 2007).

Careful feeding of the fish with a complete food provides all the nutrient needs for the fish, but since fish do not need the same levels of iron, potassium and calcium that plants need, additional supplementation of the water with chelated iron (to concentrations of ~2 mg/L) is needed (Somerville et al, 2014, section 6.2.4). Calcium and potassium levels may be maintained through additions to the water during buffering to a proper pH (as nitrification increases pH) (Somerville et al, 2014, section 6.2.4). This can be accomplished through the use of calcium hydroxide or calcium carbonate, and potassium hydroxide or potassium carbonate (Somerville et al, 2014, section 6.2.4). Additional supplementation with potassium, sulfur and/or manganese may also be necessary (Tyson et al, 2011).
Irrigation frequencies that are adequate for fish health are not always adequate for plant health. Continuous flow systems avoid this issue, but ebb and flow systems cannot be timed by the levels adequate for fish health but instead must be timed by the levels in the plant media (which will be depleted faster) (Tyson et al, 2011).

Though individual species have personal climate needs, in general plants will need a temperature between 50 and 80 degree Fahrenheit for growth. All plants need large amounts of light, with most needing between 8 and 10 hours a day for maximum production (Butler & Oebker). All plants will remove some water from the system, with large fruiting plants such as tomatoes removing more.

Dissolved salts within the water can prove harmful. Proportions greater than 0.5 million or 320 parts per million are likely to cause nutrient imbalances. Nutrients needed in large quantities are nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Micronutrients (iron, manganese, boron, zinc, copper, molybdenum, and chlorine) are needed in very small amounts (Butler & Oebker).

Although individual species have specific needs, in general fish require adequate filtration, high dissolved oxygen content, consistent temperature, and complete nutrition (Aquaponics: Fish Health). A good rule of thumb is that if the fish are not feeding, there is an issue that needs to be addressed (Aquaponics: Fish Health).
Consistent and adequate temperature is especially important, as thermal shock can easily kill fish (Aquaponics: Fish Health). Individual species will have specific individual needs for adequate temperature (Somerville et al, 2014, section 7.3.4).

Major swings in pH (more than 0.3 over a few hours) can also stress and even kill (Aquaponics: Fish Health). It is important to note that pH may lower overnight due to the production of carbon dioxide from the plants (Aquaponics: Fish Health).

In general, most fish require at least 4-5 mg/liter of dissolved oxygen (Somerville et al, 2014, section 7.3.3). However, since digital oxygen meters can be quite expensive, management of dissolved oxygen through avoiding overstocking (refraining from more than 20 kg of fish per 1000 liters of total water) and encouraging aeration through water movement and air pumps (at a rate of 5-8 L of air per minute per cubic meter of water from at least two air stones) is recommended (Somerville et al, 2014, section 7.3.3). Fish "gasping" for air at the surface of the water is a clear and urgent sign that dissolved oxygen levels are too low (Somerville et al, 2014, section 7.3.3).

Ammonia levels of over 0.25 ppm can be toxic to fish, causing extensive tissue damage (most notably gill and kidney damage), and presenting with a reddening of the eyes of the fish. Nitrite will become harmful at 0.5 ppm or higher by preventing the uptake of oxygen by red blood cells. (Nitrate) In a well-functioning system these compounds should be all but undetectable (Somerville et al, 2014, section 7.3.1). If ammonia and/or nitrite is detected, this is a sign that the biofilter (the beneficial bacteria in the grow bed) is not functioning properly (Somerville et al, 2014, section 7.3.1).

Nitrates are most harmful to fish when levels swing rapidly, so changes in nitrate levels should never exceed 50 mg/l of change in a day. Young or sensitive fish may show symptoms of nitrate shock beginning at as low as 20 mg/l, though this varies wildly by species and age (adult salmon, for instance, are known to tolerate levels up to 5000 mg/l). On average, a level of 50 mg/l is considered safe for most species, though monoculture tanks can usually withstand levels up to 500 mg/l if buildup is slow (Nitrate).

Overfeeding is another potential source of problems, as uneaten food encourages the growth of heterotrophic bacteria (thereby lowering dissolved oxygen). Uneaten food also releases large amount of ammonia and nitrite during decomposition, and can easily clog filters. In general, a good rule of thumb is to remove any uneaten food after 30 minutes and to reduce the feed amount if food is consistently left untouched after that period (Somerville et al, 2014, section 7.2.2).

In general, darkness keeps fish stress low and prevents algae growth, however sudden brightness can cause fear and stress. Thus, it is considered good practice to keep the tank in low levels of indirect light and employ darkness when handling or harvesting fish (Somerville et al, 2014, section 7.3.5).

Appendix B: Fish Species for Cultivation

The most commonly used species for aquaponics by far is tilapia because of their tolerance of a wide range of water quality, their ease in care, and their productivity as a food crop. The previous IQP team decided on blue tilapia for the aquaponic greenhouse (Chatani et al, 2015). However, a wide range of fish and other aquatic species such as prawns can be cultivated. Species selection depends such factors as the needs of the plants cultivated (different species produce different quantities of waste), the structure of the system itself (species such as catfish need shallower, larger tanks), the ranges of conditions expected (such as temperature and water quality ranges), and the value of that species in the surrounding community. Growing Power in Milwaukee, for example, has primarily cultured Yellow Perch and Tilapia, however after analysis, Growing Power determine that Yellow Perch was a preferred more than Tilapia due its taste (Growing Power, 2015). Fish cultivated need not be grown solely for their value as a foodstuff- ornamental fish such as koi can prove to be a valuable product if the market will bear them.

Appendix C: Plant Species for Cultivation

Selection of plants is from a broad base: to date, more than 150 different species have been proven viable in aquaponics systems. Flora under consideration need not be limited to just vegetables either: herbs, flowers and even small trees are also possibilities worth considering (Somerville et al, 2014, section 6.4). Seedlings produced by the aquaponics system are another possible product worth investigating, as locally grown seedlings are much less likely to be damaged in transport and can be sold at a lower price than those traditionally commercially available (Chatani et al, 2015 section 2.3.3.1.1). The type of plant grown has a large effect on the balance of the system: leafy greens and herbs require the lowest nutrient content, whereas legumes, fruiting plants and flowers can require twice as much nitrogen (Chatani et al, 2015 section 2.3.3). Balancing the needs of the community and the products grown with the capabilities of the physical system will require careful consideration. Although the previous team did touch upon this issue in their report, they did not choose a species to cultivate (Chatani et al, 2015).

Appendix D: Aquaponic Greenhouse Business Models

An essential part of creating a business is relating the investors to the social, economic, or cultural revenue. If this system is not in place, then finding people or organizations to invest in Greenvitalize (the co-op running this aquaponic greenhouse) is very difficult. But with a proper system in place, getting a business platform to a point where it creates revenue would be a natural process. Because of the community oriented nature of the aquaponic greenhouse at Worcester Roots, a community oriented business model is a key aspect of scaling up the aquaponic greenhouse (Bloom, 2010).

Cooperatives

A cooperative is a system where a group of initial investors all contribute equally at the start of a business. When a decision regarding the business has to be made, all the investors have an equal vote in the decision. Cooperatives are usually non-profit organizations, but when the business creates excess revenue it is shared among all the investors equally (Fernandez, 2010).

A benefit of this business model is that an investor is more committed to the success of the business than an investor in a non-co-op business. The investors in a co-op are responsible for the decisions regarding the co-op and directly receive the revenue created from those decisions. This structure creates a team of investors that are always working to improve the condition of the business as opposed to a group of workers who receive the same pay regardless of how successful the business is.

A negative aspect of a cooperative business model is that due to the number of responsibilities placed on an investor, finding investors is more difficult because an investor not only contributes financially to the project but also must make decisions and spend time working in the business. Another negative aspect of a co-op is that because all the investors must vote on a decision and agree on a course of action, the time it takes for a co-op to make a decision is longer than the time it would take for one person in charge (Bloom, 2010).

A prime example of a co-op business is C'ville Arts, an artistic cooperative in Virginia. The cooperative's investors are all local artists that create art and sell it at the gallery. The revenue produced by the art gallery is spent on maintenance costs and rent for the building, and the remaining revenue is distributed to the investors. In this business, a group of around 60 artists each hold an equal share of the establishment and get an equal share of the profit of the art gallery (C'ville Arts, 2011).

Another example of a successful co-op business is the Assabet Village Food Cooperative. This co-op is a grocery store that is run by locals in the community. Because the store is run by the community, community produce is emphasized and all of the produce sold in the store comes from local farms. This business model has created a way for local farmers to sell their produce without having expensive shipping costs or the need to produce an industrial amount of food. It also allows for the members of the community to easily access the freshest produce possible. All the money then stays in the local area and helps keep the local economy stable (Welcome to the AVFCO, 2015).

Community Owned Corporations

A community owned corporation is similar to a standard for-profit business structure, but with emphasis on the community. A community owned corporation has shares in the business purchasable by anyone. The decision making process for a community owned corporation gives investors a say in the decisions proportionate to the number of shares they own.

A benefit of a community owned corporation is that the decision making process can be tailored to how the investors see fit. For example, if the founder of a community owned corporation only sold 49% of the shares in the company, the founder would have the power to make every decision for the company without consulting other investors. On the other hand, this business structure could be used to mimic a co-op except instead of the investors receiving the excess products of the business, they would gain equity through the increase in the price of their shares. This model also allows for individual investors to decide on their level of commitment to the business. This expands the pool of potential investors because unlike a co-op, an investor doesn't need to be present for every decision and work on the project (Fernandez, 2010).

A negative aspect of this business model is that, because it is run more like a standard business, the workers that it employs will be less invested in its success and will not be as driven to promote and expand as the investors in a co-op. Also, in a community owned corporation, the investors are not the workers, so a level of management is necessary for the business to function smoothly (Bloom, 2010).

An example of a community owned corporation is The Community Store in Saranac, NY. The initial investors' goal was to raise $500,000 in order to open a department store in the community. Shares of $100 were purchasable by community members with a maximum investment of $10,000. The store is run by community members and the revenue is distributed to the members of the community who invested and to the workers in the store. The products available in the store are determined by community members. The community owned corporation business model has allowed the community of Saranac, NY to create a store that is run by the community and is tailored to the community's needs (The Community Store in Saranac Lake, 2011).

Small Ownership Groups

A small ownership group is a flexible business plan that accrues funds from small groups within the community. The individual investors are promised returns in a variety of forms. An example of a small ownership group is a restaurant already run and owned by a family taking small investments from the community to stay in business with the promise to return the money invested in restaurant credit. The value of this business model is that it can be adapted to fit all types of businesses. Also, the risk to the individual investor is very low, so finding investors is not as challenging as it would be for a co-op or a community owned corporation. A negative aspect of this business model is that it requires an owner and business to already be in place. Small ownership groups give new life to existing businesses, but may not provide enough capital to start a business from the ground up (Bloom, 2010).

Crowdsourcing

An effective way of accruing capital is to set up a crowdsourcing campaign. This way of funding can be used in any business plan and doesn't conflict with any of the above methods. It involves creating a prototype of the main component of your business, then marketing it to the general public in an attempt to gather investors. This method is similar to a small ownership group in the sense that a group of individuals with a business idea must already be in place and that investors are gathered from the community, but with crowdsourcing, the community of investors is global. Investors are promised rewards based on how much they donate to the business. With crowdsourcing there is a large number of investors so each investor contributes less than in any of the above business models. The benefit of this business model is that investors can casually invest in the business because of how little an individual investor has to contribute. A negative aspect of this business model is that to gain investors, your business must involve something that can affect a large amount of people. For crowdsourcing to be effective, a large pool of investors must all feel as though they will benefit from the business' success (Bratvold, 2015).

Appendix E: Organizations Interviewed

Organization Type	Organization Name	Person(s) Contacted	Summarized Findings
Key Stakeholder	The Worcester Roots Project	**Matt Feinstein** Co-director, Media and Organizing Coordinator **Shane Capra** Co-Director, Youth Development and Co-op Incubation Coordinator **Julius Jones** Co-Director, Development and Co-op Incubation Coordinator	The Worcester Roots Project provides the site of the initial greenhouse (via Stone Soup community center) and coordinates its management.
Key Stakeholder	Greenvitalize	**Howard Lucas**	Greenvitalize is the "business" aspect of the greenhouse. They will be managing the direction and day-to-day operation of the system. His vision for the future of food security in Worcester involves a large scale renovation of the current food system in place.
City of Worcester Business Network	Worcester Chamber of Commerce	**Karen Pelletier** Director of Higher Education-Business Partnerships **Stuart Loosemore** General Counsel, Director of Government	Wonderful networking resource. Mentioned other possible contacts. Warned us of potential issues with zoning (urban farming is not currently legal in Worcester, through the city is working to change this).

		Affairs and Public Policy	
Local Food Justice Organization	Worcester Regional Environmental Council	**Casey Burns** Food Justice Program Director **Brian Monteverd** General Counsel, Director of Government Affairs and Public Policy, Director of Worcester Food Hub	A very valuable potential ally/resource. Relevant programs run by REC: • **Youth Grow** Project focused on developing youth leadership. Could be a valuable source of workers. • **Local farmers markets** Currently looking for vendors. Could be a great way to sell products and help fund scaling. Implied that lack of cooperation among related food justice organizations and competition for grants/resources has been a problem in the past.
Local Educational Institution	Clark University	**Jenny Isler** Director of Sustainability, Manager of Clark Freight Farm Head of Clark Real Food Challenge **Dr. Ramon Borges-Mendez** Assoc. Professor of Community Development, Planning Coordinator of the Graduate Program in Community Development and	Suggested a focus on education may be more productive than trying to fund the project through produce. Warned about difficulty working with minors- suggested a focus on older college-bound groups. Stated that public schools may be more stringent in requirements for food suppliers. Suggested pursuing small private institutions instead. Suggested looking to National Science Foundation as a source of funding grants.

		Planning.	
	Worcester Public Schools	**Mark Berthiaume** Communication and School Support Coordinator	Confirmed that the Worcester Public school system is interested in potentially incorporating curriculum involving the aquaponic greenhouse.
Local Sustainability-minded Restaurant	Volturno Pizza	**John Amador** General Manager	Discussed food distribution in Worcester: a purveyor collects product from farms and sells it to restaurants (Volturno uses **Lettuce Be Local**). Volturno currently purchases mostly microgreens, some root vegetables and lettuce. Volturno would like to purchase larger produce such as tomatoes, but the price point remains too high and they do not have reliable seasons.
	Flying Rhino Cafe	**Chris O'Hara** Kitchen Manager	Discussed local produce purchases. Flying Rhino uses a lot of tomatoes- 6 cases a week of regular tomatoes, 4 flats of mixed color grape tomatoes a week. Flying Rhino would be interested in a cheaper/more local source of arugula and herbs (basil, tarragon, thyme, rosemary and sage).
Nearby Aquaponic Farm	Barr Family Farms (Rehoboth, MA)	**Dave Barr** Manager of Aquaponic Systems	Agreed to help establish the bacterial colony by donating used bio filter media. Stressed the importance of aeration in maintaining the health of the system. Warned us to never leave a hose in a tank (syphon effect).

			Suggested some form of backup system like a generator. Warned us of the extensive (~4 month) permitting process for keeping tilapia in MA.

Appendix F: Additional Background Research

The rise of Urban Food Production

The idea of using every square foot of soil available for the growth of food was an idea brought into American culture during times of hardship. As early as 1893 there are records of urban gardening techniques being used as a means to meet food requirements. In Detroit Michigan during this time there was an economic depression. The community came together to take control over the food system by creating local gardens in abandoned lots and fields. These gardens were called Pingree's potato patches, named for the mayor of the time (Lipp, 2014). During the second world war the idea of rationing food was created, and with it, the idea of victory gardens. These gardens were to contribute to the food available to the community during the period of intense rationing that aided the troops. Again, every square foot available was used to grow fruiting crops including window space, and back yards (Victory, 2015). Even today people are longing for the control and access over their food that urban farming brings to a community, and are starting to implement it in their communities (for example, in 2010 the world's largest rooftop garden opened in New York City (Ballard, 2015)).

The Food desert of Worcester

There are sections of the Worcester community that can only access fresh produce if they have a car that can drive them to the nearest store (as shown in Fig. 2). Not having fresh produce within walking distance or near a local bus route severely limits the ability for the community to access fresh food. Individuals in urban communities don't necessarily have access to a vehicle which makes accessing fresh produce impossible for them if they live in Worcester's food desert.

Greenhouse Structure

The final design of the aquaponic greenhouse was primarily determined by the stakeholder's needs. The stakeholder wanted the aquaponic greenhouse to function properly in both harsh winter and hot summer, thus it was important that the final design was energy efficient. Also, the stakeholders wanted the greenhouse to be constructed of local cost effective materials in order to have a larger impact on the community. Thus concepts of sustainability were emphasized in the final design (Chatani et al, 2015). The space inside the must be used properly to insure maximum food production for the local community. Analyzing the needs of local businesses and residents to determine what food should be grown in the greenhouse became an essential goal as well. Stakeholders wanted the greenhouse to act as an educational tool to help high school students and the local community get excited and involved in aquaponic greenhouses.

Appendix G: Creating an Aquaponic Greenhouse Enterprise

CREATING AN AQUAPONIC GREENHOUSE ENTERPRISE

With an emphasis on community involvement and support

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About this Guide

In this guide, the process of creating and expanding a business that revolves around an aquaponic greenhouse will be explained. The goal of this guide is to inform you of some of the promising options that exist when it comes to creating an aquaponic greenhouse and expanding from the initial pilot site. There are many different ways to construct the system and even more ways to expand outward with your enterprise, gathering community support, partnering with large institutions, and much more. Hopefully this guide will provide you with enough background for you to start exploring specific methods of creating an aquaponic system and for you to analyze the community you are a part of in a way that allows you to plan out a long term business strategy revolving around your aquaponic greenhouse.

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Introduction

This guide was constructed from various reports and interviews with Worcester Roots, a nonprofit based around principles of environmental justice and youth support, and Greenvitalize, an enterprise devoted to promoting urban agriculture and food justice in the city of Worcester. Through the process of exploring options to expand and improve an aquaponic greenhouse run by Worcester Roots and Greenvitalize, a general understanding of this process was gained. In this guide the process of creating an aquaponic greenhouse enterprise has been explained step by step to help you if you wish to pursue a similar opportunity.

How Aquaponics Works

Aquaponics is a type of farming that uses fish to create fertilizer for plants. Aquaponics works by mimicking the natural cooperation of an ecosystem. Fish produce waste that contain ammonia, which is toxic to the fish. In an aquaponic system, ammonia filled water from a fish tank is fed to plants where billions of bacteria in the growing medium break the ammonia down into nitrate. Plants use nitrates as a fertilizer and remove it from the water with their roots. This cleans the water for the fish. This natural and sustainable process produces high quality food without the need for fertilizer and drastically reduces waste.

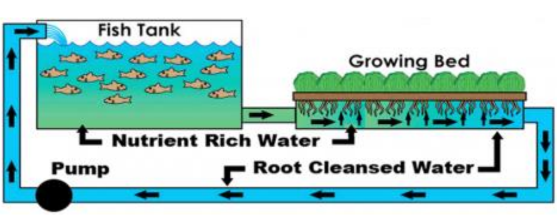

FIGURE 1: NUTRIENT CYCLE OF AN AQUAPONIC SYSTEM

Choosing a System

One of the best things about aquaponics is how adaptable it is. There are many types of aquaponic systems, and there are many ways to customize your system to best fit your needs. While there are many different setups, there are three main types of aquaponic systems: media filled grow beds, nutrient film technique, and deep water culture.

Media Filled Grow Beds

FIGURE 2: MEDIA FILLED GROW BED

This is the most common hobby method because it doesn't need a separate filter for solid fish waste but it may produce less harvest than other methods for large systems. In this method, plants are anchored in one or more containers with grow medium, an inert material that provides the plants with a foundation in which to grow and anchor their roots. Examples of grow mediums include pea gravel or small clay balls. Grow medium also moderates the temperature around the plant roots, provides a surface area for the nitrifying bacteria to grow, and mechanically filters out the solid waste from the fish. Within this method, you have three major considerations to determine, as discussed below.

What type of container do you want to use?

Smaller containers like five gallon buckets are great for smaller or odd-shaped spaces, but can be too shallow or small for plants that have bigger root systems. Woody plants, such as trees or shrubs and tall plants like corn usually need more room than smaller plants like herbs. Make sure you have enough room for the plants you want to grow.

What type of media do you want to use?

Heavier media like pea gravel provides better support for tall plants. More porous materials like rock wool and clay balls offer a better place for the beneficial bacteria to grow. Smoother materials are softer on your hands and easier to work with. No matter what material you use, you should rinse it first to remove any contaminants, make sure it is big enough to not slip through your drains and clog your pipes. Also, make sure it won't release pollutants into the water.

What kind of water system do you want?

There are two types of water systems available for a media filled grow bed: *Ebb and flow*, and *constant drip*. Ebb and flow works by using a syphon to drain the media when it reaches a certain point. Constant drip uses a constant water flow both in and out of the media at the same rate. Ebb and flow tends to have better aeration because no part of the system is always underwater. Constant drip is easier to implement, but can result in areas constantly underwater that cause root rot.

Nutrient Film Technique

FIGURE 3: NUTRIENT FILM TECHNIQUE

This system is easiest to implement if you're adapting an existing hydroponic system. In this method, no grow medium is used. Instead, the setup is adapted from hydroponic techniques. Gutters are set up with holes cut out of the top to put plants in, and the plants sit in the gutters with water trickling over their roots. This system isn't great for plants with large root structures or that need a lot of support since there is little for them to anchor to and large roots can clog the pipes. The water must also be filtered before running through the pipes. Otherwise, particles of waste can stick to roots and create anaerobic areas, leading to root rot. In general, plants that do well in traditional hydroponic systems, like lettuce, will work well here. If you use this method, make sure that your pipes are wide enough to not get clogged.

Deep Water Culture

FIGURE 4: DEEP WATER CULTURE

Also known as the floating raft method, this technique floats rafts with holes cut out of them on top of water. The plants grow in these holes, using the raft for floatation while their roots dangle in the water. Like the nutrient film technique, you should make sure to filter solid waste out before the water reaches the plants. Otherwise, waste particles can stick to roots and create anaerobic areas, leading to root rot.

Deep water culture is the most popular commercial method since it allows for large amounts of crops to be grown easily. This technique uses a conveyor belt method to harvest plants. In this method, there is a long, shallow channel in which rafts are placed. The rafts are cycled through the channel with seedlings entering at one end, and plants ready for harvesting exiting at the other end. The large amount of water needed for this technique is also great for the fish because a large amount of water is less susceptible to rapid changes in water quality and temperature. However, this method is difficult for small spaces.

No matter what method you choose, you will need:

- A tank for fish
- A structure to house the plants
- A water pump
- Piping to connect everything
- A water quality test kit

Make sure your materials won't contaminate your water. Aquarium suppliers are a good resource for things that won't hurt your fish, but hardware stores can be much cheaper. You might also want to consider getting equipment to provide some sort of automatic monitoring or back up, like a battery backup or gas generator for your water pump, or a way to alert you if something goes wrong.

Choosing the Species

Different species require different care and are suitable for different environments. Make sure you verify that you can provide the environment that the fish and plants you choose to grow need. Choosing carefully to ensure that the species you use are compatible with each other and the climate that you're growing them in is essential for maintaining a healthy aquaponic system.

The two superheroes of the aquaponic world are lettuce and tilapia. These are the most commonly produced crops because they are easy to grow and maintain. If you're unsure of where to start, these are a great first choice.

Types of Plants

Different plants will require different types of nutrients, temperatures, levels of sunlight, and structural support. Watch out for large fruits and veggies. They will likely need to pull much more water from the system, requiring you to keep a close eye on your water level to keep your fish happy. Things to know about a plant species before you choose it include:

- **Temperature**
    - What temperature range does this plant thrive at?
- **Light requirements**
    - How much light does this plant need to be healthy?
- **Space requirements**
    - How much room do the plants need between each other?
- **Water quality**
    - Does this plant require a lot of water?
    - Does this plant require additional nutrients to be added to the water?
- **Edibility**
    - How easy is it to harvest this plant?
    - Is it good to eat?
- **Price**
    - How expensive is it to purchase seeds or seedlings?
    - How much can each plant be sold for?
- **Legality**
    - Is it legal to grow this plant where you are?
    - Do you need a permit?

Types of Fish

Different fish will react differently to changes in water quality and temperature. Some fish are fragile while others are more durable. Things to know about a fish species before you select it include:

- **Temperature**
    - What temperature range is ok for this fish?
- **Breeding**
    - How easy is it to breed this fish?
- **Space requirements**
    - How big does the tank need to be?
    - How many fish can you have in the same tank?
- **Water quality**
    - How resilient is this fish to changes in water quality?
    - How easy is it for this fish to get sick?
- **Aggression**
    - Will having certain combinations of this fish at different ages, sexes, and stocking densities be a problem?
- **Edibility**
    - How easy is it to prepare this fish?
    - Is it good to eat?
- **Price**
    - How expensive is it to get babies?
    - How much can you sell them for as adults?
- **Legality**
    - Is it legal to keep this fish where you are?
    - Do you need a permit?

It's worth mentioning that you don't necessarily need to stock only one type of fish. Some fish work well with other types. You don't necessarily need to grow fish. Other aquatic species like crayfish can be a good alternative. You also don't need to only grow edible species either. Ornamental species like koi and goldfish can be a beautiful and rewarding alternative to food crops and they can command an impressive market in some areas. Key favorable species for easy maintenance are typically tilapia and lettuce. Key favorable species for profit are typically koi fish and microgreens.

Getting Organized

When starting a venture such as an aquaponic greenhouse, there are many options to consider beyond the choices of system type or species to populate your aquaponic greenhouse with. The larger scope of why you are establishing this greenhouse should also be considered as an integral part of the process of creating an aquaponic system. Some main considerations are: choosing a goal, deciding on how to involve the community in your project, organizing a source of funding for the operation and maintenance of the aquaponic system.

Establishing a goal

You should consider three main goals as possibilities when starting your aquaponic greenhouse. One potential goal is a food hub platform in which your crops are the primary source of revenue. A second potential goal is an educational platform in which your crops are not used primarily as an economic output but as more of an auxiliary output of educational programs. The third goal could be to form a community-building space, which is a hybridization of goals one and two with a large emphasis on community involvement and improvement. The goal you pursue will affect the structure of your aquaponic greenhouse.

Pursuing Food Justice

Your aquaponic greenhouse can become part of a food hub and contribute to food justice in the community. Pursuing food justice focuses on the needs of the community that are not being met by the conventional food distribution system. This means that you would focus on creating produce that members of your community don't otherwise have access to, such as traditional Asian fruits that are not available at the supermarket. If the goal is to focus on food justice, than your greenhouse should optimize the amount of growing space available in order to provide the largest benefit possible. You should stock your greenhouse with species that are culturally significant to a local population that doesn't otherwise have access to the produce you grow.

Education

If your goal is to create an educational platform there are many considerations that come into play. The best-suited community for this goal will have a variety of different schools that can benefit from outside educational programs. Something to consider is the curriculum involving the aquaponic greenhouse. If the curriculum revolves around the nitrogen cycle, the fish should be in an aquarium that the students can observe. Other possible curriculums the aquaponic greenhouse can be integrated with are curriculums that focus on food justice and sustainability. This style of aquaponic greenhouse would put more emphasis on food production so the variety of produce can be showcased. If you create a curriculum that focuses on entrepreneurship and small business ownership then the greenhouse would need to be designed with all the means of production in one place for the students to understand the process of growing and selling a product.

Community Development and Innovation

A final possibility for the ultimate goal of your aquaponic greenhouse may be to open it up to the community for experimentation. By allowing members of the community to try new ways to grow and harvest produce, you can facilitate of an emerging form of community development and innovation. This is the platform for a makerspace in which the community can participate in experimentation that ultimately leads to food justice, education, and serves to unite those with a similar interest and goal. This space would educate the participants on the applications of aquaponic systems and possibly inspire them to construct their own. If this is your goal than your greenhouse will need a lot of empty room for people to work and learn. The grow beds and fish tanks in your system should be easily accessible and easy to transport because of people frequently experimenting and testing new modifications of the traditional system.

Establishing Partnerships

It is essential to the successful of an aquaponic greenhouse that you find some community members to partner with. Community members can aid many different aspects of your overall goal. Some members may contribute to the business aspects of the greenhouse while others may help in the maintenance and upkeep aspects.

The participation of the community will be vital to the success and impact of your aquaponic greenhouse directly or indirectly. There are organizations within every community that have goals similar to yours and it is important to find them. Skilled experts in your community can provided innovative perspectives on the operation and purpose of your aquaponic greenhouse. With your local organization devoted to environmental issues you can learn about the regulations pertaining to food production. In certain cases the city may have restrictions on food grown in the soil for resale based on zoning laws and quality tests. It is important to contact these types of organizations early on in the creation of an aquaponic greenhouse to get an idea of the type of obstacles you may be facing and to explore opportunities such as collaborations and grants.

Contacting your local business community, such as your chamber of commerce will provide you with information on producers and distributers of produce similar to yours within your community. In the search for more information, you can seek out experts on aquaponics and food production in your community so that they can point out the many challenges of providing food for your region.

Contacting experts from the growing community and universities is your area will help you prepare for barriers that you would otherwise have to discover on your own, potentially saving you from wasting a lot of time and money solving a problem that could have been avoided.

Finding Funding

A large part of beginning an aquaponic greenhouse enterprise is deciding on what types of funding you desire and pursuing those funds. The avenues of funding change depending on your community and your goals. The main avenues of funding are investors and grants. Investors are individuals that offer their time or money to help get your enterprise started and grants are large sums of money given to you by a large organization. Both help to start the process of creating your aquaponic greenhouse enterprise.

Attracting Startup Investors

There are many different types of investors. Some investors are purely interested in return on investment, meaning that they want you to pay them back a greater amount of money than they gave you. Others are interested in promoting their own interests through advertisement and partnerships. The third type of investor invests in your project because they want to promote the goals of your organization. This kind of investor is interested more in helping the community and less on helping themselves.

Depending on your goal you should pursue different types of investments. If you are purely interested in selling produce to make profit than an investor that wants a return on investment maybe your only option. If you focus on helping the community, either with the produce you grow or by involving different groups within the community in the maintenance of the aquaponic greenhouse, than this opens up the possibility for more ideal investments. If you are helping the community with your aquaponic greenhouse than individuals that work on similar projects may invest their time into helping set up the project as well as donate money for the purchasing of materials. For example, if one of your goals is to keep youth off the streets, than an organization that prepares underprivileged youth for future jobs is likely to invest in your enterprise because you will eventually be helping them by training youth at your facility. It is key to look for investors that have goals similar to yours because they are more likely to offer support.

Obtaining Grants

If there is an aspect of community support in the goal of your aquaponic greenhouse enterprise than there is the opportunity for you to pursue grants. Grants are usually awarded to organizations that strive to benefit the community through education or through providing things to individuals who would otherwise not have access to such things. In the context of an aquaponic greenhouse, if you want to obtain grants, your goal should focus on either providing food to the hungry, or education. If these are your focus than there are grants like the EPA environmental education grant that you can pursue. Companies like Google, Kraft, and Kellogg also award grants to organizations that work to feed the hungry. Large grants like these, as well as smaller local grants in your area, are great sources of funding at the beginning of your enterprise.

Finding a Market

Finding a market can make or break the idea of establishing an aquaponic greenhouse in your community. Without the proper market, the success of the system is limited to your own personal time, contribution, and funding. Marketing to benefit the community is also the best way to make a positive change in your community. Some of these marketing strategies involve getting involved with local educational programs and donating the food produced to local charity.

Selling to Local Businesses

Selling produce to local businesses is a great way to get your community excited about your aquaponic greenhouse. Many local businesses prefer fresh ingredients as opposed to ingredients containing preservatives. An aquaponic greenhouse can constantly create fresh produce, which is often preferred by chefs to create quality meals. Local business can give vital information when you are deciding on which produce to grow. Most businesses will purchase microgreens from small scale greenhouses. By asking the business what produce they need you can tailor what food you grow to the demand from local businesses. This strategy will prevent you from growing produce that local businesses do not sell. Local business can act as primary generators of revenue for the greenhouse.

Fish and plants can be sold to local markets or to local restaurants depending on where the demand is. An aquaponic greenhouse has the option to grow produce specifically for the local market. Being the only supplier of a culturally significant type of food will not only create a lot of economic revenue for the enterprise to reinvest in development, but will also provide cultural revenue by being able to provide a group with food that has emotional significant to them. When bringing your harvest to market it is important to start small and build from there. For example, make a deal with one corner store to provide fresh lettuce for the side salads they sell. Even though it seems like a small commitment, it's important to gauge how much produce you can deliver before you make large contracts with restaurants.

Alternately, your aquaponic greenhouse could grow ornamental species as well as or instead of edible produce. Breeding tropical fish for aquariums within the aquaponic system could be more profitable than breeding perch or tilapia for food. Swordtails and Koi fish can be used in aquaponic systems as well as many other species of ornamental fish. If ornamental fish are bred instead of edible fish, the amount of financial revenue created from each fish increases. This has to be balanced with the social and cultural revenue of providing fresh fish to a community that potentially has no other access to fresh fish.

Ornamental plants such as flowers or ferns can be grown instead of food crops. The potential for this to be effective depends on whether or not the climate of the aquaponic system is suitable for certain ornamental species and, like with ornamental fish, the financial, social, and cultural revenue created from the plants must be balanced at a point the investors see fit. If these factors are considered, ornamental plants can be a good way to increase profit.

Educational Programs

Integrating your aquaponic greenhouse with a school's curriculum could provide you with the means to increase profits via educational programs. One way to integrate your aquaponic greenhouse with a school's curriculum is by creating a program on modern farming techniques. This would require that the school has a flexible curriculum that could fit a new module into the existing structure. The curriculum could focus on introducing the students to the rich history of initiative in the United States that began as far back as the World War I era. The curriculum could also focus on contemporary food issues in urban areas, including the issue of food deserts, places in which low income sections of cities do not have access to fresh produce.

A final note of direction for your educational platform is to consider targeting private institutions when bringing the idea of curriculum integration to fruition. This is advised because private schools have less government regulation which allows them to fit more creative topics and activates into their curriculum. Public schools are more concerned with meeting the ever growing demands of standardized testing while private institutions may be more open to a new approach to education.

Donating to Food Charities

When using an aquaponic greenhouse as a source of education for the community, it is important to note the auxiliary output of produce that is a byproduct of this system. This fresh produce should not go to waste just because it is not the main goal of your aquaponic greenhouse enterprise. The idea of donating food to charity seems simple but in actuality, can be rather challenging. The main obstacle can be the preparation of the food for consumption which is regulated throughout the United States by the FDA. This can be overcome through the use of a local food bank's commercial kitchen. Food bank's for farmers markets and other purposes require an efficient way to meet the FDA regulations for eatable produce, and the solution is a commercial kitchen that will screen the massive amounts of produce and prepare it for consumption. The commercial kitchen would have to be contacted early on and become a major partner in order to ensure the viability of the donated food.

Selling to Anchor Institutions

Anchor institutions are large institutions that require a lot of produce to support the members of the institution such as nursing homes, hospitals, universities and local schools. Anchor institutions have the highest demand of all of the potential markets for your produce. A contract with an anchor institution will provide you with lots of revenue, but also require that you can meet their large quota. Anchor institutions require that your enterprise can meet such demand before guaranteeing a partnership. The ability to produce a lot of food on a large scale is necessary before contacting anchor institutions about a possible partnership. If your aquaponic greenhouse enterprise possesses the means to partner with an anchor institution, this partnership can give you stability and constant growth and it can give the anchor institution publicity for involvement with community. Ensuring positive publicity for the anchor institution is key for partnering with anchor institutions.

Expanding the Enterprise

Once you have a working system, a business plan, and a community that is willing to work with you, the next steps are to plan for expansion beyond the pilot site. This expansion helps to increase the influence your organization has over the community and increases the benefit that you can provide to the community. Expanding takes many forms, primarily though partnering with larger organizations, creating multiple sites, and building up your site into a larger scale production facility.

Physical and Modular Structures

Scaling up often refers to increasing the size of current operation. There are two major ways to increase the size of your initiative. Creating larger facilities and increasing the number of sites that are part of the enterprise. Each method of scaling up has its benefits.

A large facility will allow operators to maintain all produce in one facility. One large facility can have a positive impact in the local community. Having a large facility can have tremendous educational value simply because a large facility has the capacity to sponsor tours and host education programs for the youth. A large facility can also use more efficient growing methods and create more produce which gives you access to economies of scale. However, the cons of a large facility include ensuring produce does not contract a fungus, endangering all your produce, and dealing with more restrictive regulations in place on larger facilities. These restrictions make it essential to monitor the health of each crop. Also, certain policies may prohibit large industrial greenhouses due to zoning laws. Thus it is important to check local zoning laws before increasing the size of your current operation to one large facility. It is also important to mention the cost of upgrading to a large facility. This kind of change takes time and effort and although it may be worth it, take into consideration the time and money to create the structure you envision.

Modular Structures

Increasing the number of small aquaponic systems may be a preferable method of expansion for you if you live in a densely populated, developed area. Small greenhouses can have a significant impact due to their strategic placement in a neighborhood. The placement of greenhouses can get the local community excited about your enterprise and about aquaponic greenhouses in general. You can partner with local schools and other organizations with empty space on their property in order to find room for more aquaponic greenhouses. This process can also allow your organization to apply for educational grants, which can fund a portion of the new aquaponic greenhouses you create. Many small aquaponic greenhouses build resilience into you enterprise because if one greenhouse has a catastrophic failure, the others act as backups.

Conclusion

By reading this guide we hope that you are more prepared to approach the challenge of creating an enterprise revolving around the use of aquaponic greenhouses. Although this guide doesn't go into specific details about any one aspect of the process of scaling up, we hope that this guide has provided you with enough background knowledge to know what options you need to explore more thoroughly. Remember to always stay positive. Good luck!

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