System analysis of a high-value aquaponics innovation in Ontario

By

Mashiur M. Rahman

A Major Research Paper
Presented to
The University of Guelph

In partial fulfillment of requirements
for the degree of Masters of Science
in
Capacity Development and Extension

Guelph, Ontario, Canada

ABSTRACT

System analysis of a high-value aquaponics innovation in Ontario

Mashiur M. Rahman
University of Guelph, 2016

Advisor:
Dr. Helen Hambly Odame

This research paper examines the system of aquaponic farming for sustainable food production in Ontario, Canada. Currently, aquaponics is becoming quite adaptable and amenable globally for community-led social enterprises and capacity building. The literature review discusses stakeholder's perceptions and awareness, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of aquaponics farming and its commercial viability in Ontario, Canada, and two commercial aquaponics case studies in Ontario. The objective of this paper is to explore the sustainability and feasibility of aquaponic farming in Ontario for the purpose of improving food security. Sustainable aquaponic operations rely on careful analysis, planning, and management of resources. The case studies demonstrate that aquaponic operations in Ontario are social, environmentally and economically viable. Ultimately, community-based sustainable aquaponic farming will be a viable solution for food security for an increasing population globally. This study is significant because it describes the sustainability of commercial aquaponic farming in Ontario. However, further research is needed to help minimize energy costs and provide economically affordable fish feed to ensure profitability in aquaponics.

Key words: aquaponics, fish, tilapia, closed-loop systems, economic development, sustainability, recirculating aquaculture system, hydroponics

Acknowledgements

First and foremost, I would like to extend my deep gratitude to my advisor Dr. Halen Hambly Odame for her enthusiasm, guidance, and encouragement throughout the program in so many ways. My sincere appreciation to my committee member and instructor, Dr. John Fitzsimons, for his cooperation and recommendations. I would also like to thank Steve Naylor, Aquaculture Specialist, and Aquaponics Specialist, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), for his incredible support and for connecting me with aquaponic specialists in the industry. I also thank (REDACTED NAMES) Green Relief aquaponic facility. I would also like to thank the incredible support staff in the SEDRD department, particularly Patricia Van Asten, Graduate Program Assistant, for her coordination.

I would like to thank my family Haleemah Rahman, Wasi, Wafa and Zaida for their inspiration and cooperation. I respectfully acknowledge my other family members for their tireless support. I value the encouragement from my friends throughout my academic and professional life.

TABLE OF CONTENTS

Abstracts

Acknowledgement

Figure and Table:

Chapter 1: Introduction

1.1 Background

The world's population is expected to increase to 9.7 billion by 2050 (UN report 2015) and simultaneously, 50% of arable land in the world may become unproductive for agriculture. To feed this growing population, food production needs to increase by 110% (Okemwa, 2015). It is impossible to maintain dietary needs without innovative food production techniques, hence the need to find innovative systems to increase the productivity of agricultural commodities through the efficient utilization of land, water, and other resources.

Aquaculture, the artificial culture of fish, is the fastest-growing area of the world's food-producing sector, representing approximately 50 percent of global fish production. Canada's Department of Fisheries and Oceans (DFO) (2012) reports that in 2010, world aquaculture production involved approximately 77 million tons of product valued at US$125 billion. Aquaculture in Canada has grown recently and increased in value from US$318 million to US$767 million between 2000-2012 (Food and Agriculture Organization 2014). Hydroponics is a soilless plant production system, considered as being environmentally friendly compared to traditional plant production methods (Cunningham, 2015). Aquaponics is the relatively newly innovated production system combining fish (aquaculture) and plants (hydroponics) using water recirculation of 95-98% (FAO, 2014).

Worldwide, most of the degraded land is lost as a result of erosion and human activities, and the arable land area is shrinking because of urbanization and sea level increase. Kulak et al. (2013) estimated that food production is responsible for 20-30% of greenhouse gas emissions and agriculture is one of the causes for climate change (Eigenbrod & Gruda, 2015). It is necessary to develop innovative alternate agricultural systems to meet the demands for

environmentally sustainable food production systems and global food security (Foley et al., 2011). In this connection, Eigenbrod and Gruda (2015) recommended limiting the agricultural expansions in tropical forests, increasing yields in underperforming landscapes and increasing agricultural research. In addition, to better utilize the land, Eigenbrod and Gruda (2015) suggested using the vacant land in the cities for food production to solve future food demands.

1.2 The importance of aquaculture and its limitations in Canada

In Canada, aquaculture producers practice a variety of culture systems; however, the major type of production is cage culture of Atlantic salmon and blue mussels from submergible suspended longlines. Aquaculture is argued to have even greater potential including a major role in supporting and energizing Canadian coastal and rural communities. Approximately 14,500 full-time jobs are generated by the Canadian aquaculture industry. As well, there are few socioeconomic studies in Canada with regards to how communities are engaging in aquaculture and innovation in order to create and sustain jobs and support local and regional economies.

In Ontario, aquaculture plays a growing economic role, and product awareness has increased somewhat among the general public (https://www.ontario.ca/foodland/food/fish). About 80% of Ontario's aquaculture production comes from open water cage farming from Lake Huron and Georgian Bay (Moccia & Bevan, 2009). Despite conductive internal production factors such as increasingly cost-efficient technologies, aquaculture in Ontario can face challenges due to limitations such as low market penetration, thus reducing profitability and causing a lack of new investment (Moccia & Bevan, 2007).

The available literature suggests that both the Canadian and Ontario governments are committed to enhancing fish farming and its sustainability through enhanced research and

knowledge mobilization (Strategic Plan, 2005). Aquaculture would benefit from a thorough mapping of the various actors within its innovation system. The sustainability of Ontario's aquaculture production is specifically connected to its financial feasibility, consumer demand and its development and support within rural communities (Moccia & Hynes, 1998). Job creation and linkages within the sector to local markets and even global trade should be considered. Proper governance, administration, and development of new sites play an important role in the sustainability and future of aquaculture in Ontario and the rest of Canada (Moccia, Bevan, & Osuchowski, 2010). Aquaculture sustainability is also related to social, environmental and financial awareness and action among the wider public in Ontario. Urban farming can significantly benefit the economy, food security and social fabric of a city/municipality. Kazakevich (2013) described different literature which addressed the importance of social, economic and environmental benefits of urban farming and their limitations in Southern Ontario. The major concerns are profitability, available land, zoning, regulation, and development policy.

Dustin (2014) mentioned that local fisheries create employment, are self-dependent to avoid import and action against overfishing, and exhibit a positive response in food security. However, Klinger & Naylor, 2012 reported that aquaculture has a negative impact on climate change because it may "severely degrade aquatic ecosystems, pose health risks to consumers, reduce incomes and employment in the capture fisheries sector, and diminish food resources for poor populations". As identified in the various articles, aquaculture influences major negative impacts on the environment through: 1) Water pollution from aquaculture run-off such as, chemicals, antibiotics and excess nutrients (fish feed & waste); 2) destruction of indigenous fish species by introducing foreign and invasive species; 3) unplanned entrepreneurship in the local communities may cause disease, encourage predators, etc.

1.3 The innovative technology needed in this sector

Regarding agricultural innovation and rural economic development activities, aquaculture should explore "triple loop learning" that identifies stakeholder groups and determines potential knowledge brokering efforts including innovation platforms, public awareness campaigns and action learning (Klerkx, Leeuwis, & Cees, 2009). If sustainability and success of the aquaculture sector are to be achieved, a review of the system is needed to successfully operate a stakeholder's platform for knowledge sharing, information, and communication. It can be dynamic and bring to light how different parts of the aquaculture sector operate and how actors carry out aquaculture activities as well as relevant external relations and the interactive learning processes that need to be involved in aquaculture innovation. Such a review also provides input for policy makers on how to strengthen the aquaculture sector system, a sector with the potential to become even more knowledge intensive and innovative (Summerfelt & Christianson, 2014). Researchers would progressively encourage people to support new frameworks, design/redesign and radical advancement methods with expert vision and insight into new agricultural technologies (Klerkx, 2010). Tyson, et al. (2011) stated that "because of public concerns over energy and water use in agriculture, technological and cultural innovations that reduce the ecological footprint of aquaponics systems will be welcomed". He also mentioned that it is important to find innovation for alternate food sources which are affordable for the community, nutritious as food and available for the local community.

1.4 The importance of aquaponics in Canada

Aquaponics is a combination of symbiotic production of aquaculture (fish, prawns, crayfish etc.) and hydroponics (plants and vegetables). Neher (1992) characterized sustainable

agriculture as an environmentally friendly food production system fulfilling the following mandatory components: “plant and animal productivity, environmental quality and ecological soundness, and socioeconomic viability” (Dustin, 2014). Aquaponics has social, economic and environmental benefits; therefore, stakeholders are interested in this new innovative food production system. On every continent of the world, 43 countries, are practicing aquaponic farming (Love, Fry, Genello, Hill, Frederick, Li, & Semmens, 2014). In Ontario, ten aquaponic (appendix – 1) farms have been identified from various sources.

Aquaponics is growing in popularity due to its environmental, social, economic and health aspects. Aquaponic farming can range in size from a small garage and backyard to a commercial large tank system combined with a greenhouse and open-environment system. The essential slogan for promoting the popularity of the aquaponic concept is: “grow your own healthy more affordable food.” As an innovative modern technology, aquaponics positively contributes towards the production of nutritious and healthy food. Concerning food security, consumers are conscious about their food selection and aquaponic farming systems can meet their needs.

Recently, aquaponics education is gaining attention in schools and Nelson and Pade, Inc. as outlined in a comprehensive aquaponics curriculum for the interested schools. This curriculum system covers design, plant and fish selection, fish and plant nutrition and experiment maintenance. A guideline designed for the teachers through the Cornell Science Inquiry Partnerships Program describes small-scale aquaponics management (Hart, Webb, & Danylchuk, 2013). This study evaluates the sustainability of aquaponics farming for innovative food production systems and makes a comparison with existing aquaponics in Ontario.

1.5 Goal and Objectives

The goal of this research is to explore the sustainability of aquaponics as an alternate food production system in rural and urban Ontario, Canada for the purpose of food security.

The objectives of this research paper:

1. To determine the sustainability of the current aquaponic systems in Ontario and their social, environmental and economic benefits
2. To analyze the opportunities, needs, and challenges facing aquaponics stakeholders in Ontario

1.6 Methodology:

This section outlines the foundation for the research approach adopted and the selection of specific cases in more detail. The overall design and structure of the case studies were discussed in the comparative perspective of the study. To better understand how Green Relief (GR) and Aqua Greens aquaponics are connected to progressive conceptions of sustainability and food security, the author volunteered for three months at GR and Aqua Greens in 2016 conducting fieldwork. This field work involved performing maintenance of the facility, taking care of fish and plants, and having discussions with the employees and owners to learn about the system. The author also visited Aqua Greens' production facility with the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) research team. This contributes to part of this study with respect to understanding the processes and the functions of aquaponic systems. We also reflect on the limitations in collecting information for the case studies, which may affect the objectives of this research paper. The primary goal of this study is the exploration of an innovative systems approach to identify, map and analyze Ontario's aquaponics production and value chains in order to determine the needs of small and medium producers, including giving

attention to the knowledge of science, capacity building, and networking potential. There are few studies that describe small-scale, community, urban aquaponic enterprises, and in particular, the sorts of conditions that affect their sustainability. This study employs a cross sectional, comparative case study approach to examine the sustainability of aquaponic farming in Ontario.

This study consists of a literature review to provide background information on food supply issues, aquaculture, hydroponics and finally aquaponics in Ontario. This paper compares different methods of agriculture in the next portion of this paper to provide a basic understanding of the complexities of agriculture.

Since aquaponics combines two food products in its operations, a case study for each of these separate products, fish, and vegetables, were provided so that the resources needed to produce these two products separately can be compared to when they are produced in conjunction. The qualitative analysis of aquaponics is based on sustainability, financial feasibility, and healthiness. Financial feasibility was selected because food prices can determine the kinds of foods that people have access to. Affordable food prices can increase people's access to healthy food to avoid malnutrition. The construction, maintenance, and operation costs determine whether food producers will use a particular method of production; if a production method is not financially viable it is not going to be used. Sustainability was chosen because future resource needs will be affected by present consumption. As the population grows, increased amounts of resources are going to be needed to meet food needs, and sustainable food production methods used and developed now can potentially ensure that resources will be available in the future. Sustainability also includes a food production method's effect on the environment; a method that negatively affects the environment compromises access to resources in the future such as clean water and air. The healthiness of a food includes the overall nutritional

content as well as the lack of potentially harmful chemicals from the use of chemical fertilizers, pesticides, and herbicides. The use of chemicals to aid in food production has the potential to be harmful to health.

Two case studies were analyzed. One is Green Relief (GR), a licensed producer under Health Canada's Access to Cannabis for Medical Purposes Regulations (ACMPR). The other is Aqua Greens, a commercial aquaponic producer, using an operation utilizing a recirculation system to raise fish, and organic vegetables. Both these aquaponic systems are producing tilapia fish in a recirculation system but GR produces medical marijuana while Aqua Greens produces various herbs and vegetables.

1.7 Significance and Limitations

The findings of this study will examine the benefits to society considering that aquaponic farming as one potentially viable mode of operating one's own food production system for improving food security. In addition, through aquaponic farming, urban and rural communities can improve the social, environmental and economic factors that are necessary for food security. The purpose of this research paper is to describe the sustainability of commercial aquaponic farming in Ontario. This study will be a significant contribution in promoting aquaponic farming to solve water scarcity, soil depletion and increase the availability of desired food production in urban and rural areas. This study will be helpful in creating more entrepreneurs in aquaponic farming to move this method forward and allow it to play a key role in sustainable food security and economic development. In addition, to minimize food prices and transportation costs, aquaponics is ideal for urban farming. The output of this study is a source of material for the small holder to establish a small-scale aquaponic system for their own food production. It will

also serve as a future reference for researchers on the subject of sustainable food production systems for food security.

There were a few limitations with this particular research paper. One of the selected aquaponic farms, Green Relief, is strictly monitored by Health Canada. The research ethics board at the University of Guelph did not approve the non-disclosure agreement for security purposes. Therefore, we were not permitted to collect sufficient data from Green Relief for this study. Most of the information in these case studies are based on news media, the company's website, and personal observations.

1.8 Overview of the Paper

The structure of this research paper is comprised of four chapters. Chapter one provides the introduction to the paper, the goals, concepts and important terms. Chapter two is a literature review of sustainable agricultural systems and innovative alternate food production systems. This chapter also includes a SWOT analysis and discusses the advantages of aquaponic farming over conventional farming systems. Chapter three provides two case studies on commercial aquaponic farming in Ontario. Chapter four discusses the overall findings of this paper, draws conclusions and makes recommendations for future research.

Chapter 2: Literature Review

2.1 Introduction

This chapter will review scientific articles on, food security, aquaponic production systems, aquaponics in Ontario, and measure sustainability in the aquatic-based food production system. In addition, a SWOT analysis on aquaponic farming is discussed. At the end of the chapter, a conceptual framework is discussed to provide direction to manage research work chronologically.

2.2 Food security and aquaculture

Food security is defined as a failure to solve the global hunger, increased food crises, and as a social movement trying to redefine what the concept means to them (Dustin, 2015). Sustainable food production systems can improve food security through the availability of food, access to food and quality of food. Self-production of food in home or community gardens can increase nutritional food, food security, petty cash and self-consumption (Eigenbrod & Gruda, 2015; Kortright & Wakefield, 2011; Lovell, 2011). Foskett (2014) reported referring from World Food Summit of 1996, the conceptual structure of food security is an accumulation of different ideas to achieve food security via the "four pillars of access, availability, stability, and utilization". The different author acknowledged that providing socioeconomic and environmental benefits are the primary condition of the sustainable food system (Eigenbrod & Gruda, 2015). Aquaponic farming is recommended for food security for various reasons; to: increase organic local production, reduce dependency on food transportation, and generate organic production. As a form of organic food production system, aquaponics is gaining interest in many countries.

Worldwide, aquaculture is important for food security and nutrition (FAO, 2015). In Ontario, the sub-sector is relatively small and dispersed (OMAFRA, 2015). Understanding the context and stakeholders, their functions, and the prospective actors for this activity are essential within this sector. This requires the identification of key stakeholders who are currently part of the market chain of aquaculture in Ontario; including their roles, responsibilities, needs, and contributions. Ontario aquaculture is dominated by a small number of large firms. One of the approaches in this study is to focus on other aquatic producers (e.g. organic aquaponics) who currently are a small sub-section of producers.

2.3 Aquaponics and its current application

Aquaponics brings together the practices of aquaculture (growing fish) and hydroponics (growing soilless plants) that mutually benefit both environments where 95-98 percent of the water is recirculated (FAO, 2014). In an aquaculture system, wastes accumulate in the tanks and eventually must be removed to maintain the health of the fish. These by-products contain rich nutrients that plants filter up, which allows the water to be recycled, then it is sent back to the fish tank to start the process all over again. Every gallon of water in the fish tank can have half to one square feet of grow bed base depending on fish density and feeding rate, and for every one-pound fish to be raised, 1-2 gallons of water are needed. An aquaponics system is scalable from small individual use all the way up to a large commercial operation. An initial investment for equipment can range from a few thousand to several thousand depending on the size of the operation. The idea of urban farming such as aquaponics where crops are grown in water beds likely changes the perception of urban dwellers. In addition, aquaponics could be considered as a hobby for those who enjoy maintaining aquariums at home. In aquaponics, besides the

recreation, one can obtain some economic advantage. In developing countries such as in Bangladesh, in urban, semi-urban and rural areas, aquaponics is being practiced to produce more fish and vegetables (Salam et al., 2016).

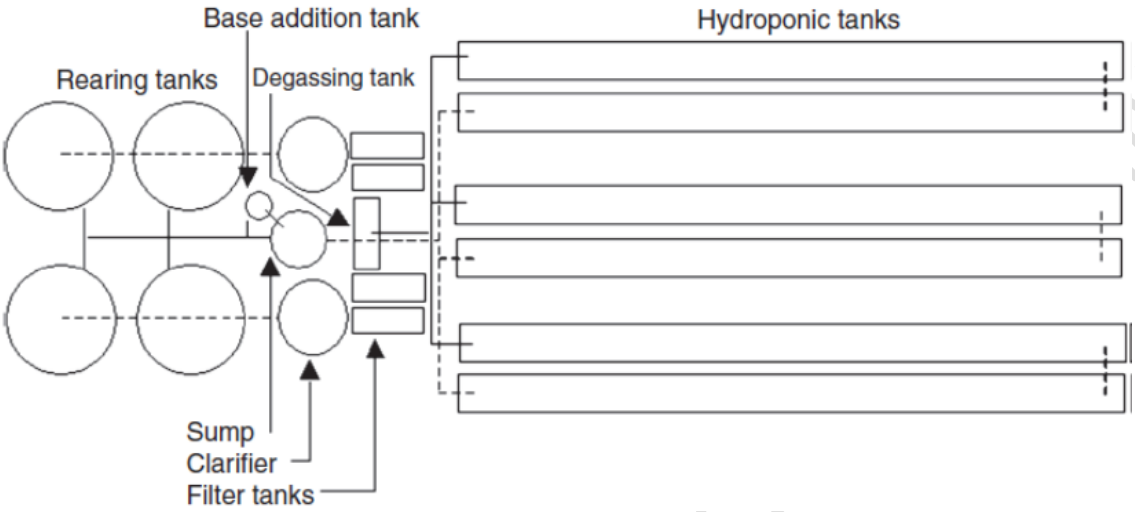

Fig – 1: Layout of University of the Virgin Islands (UVI) aquaponic system (Rakocy, 2012)

2.4 Aquaponics in Ontario

Although aquaponics is a very sustainable innovative food production system, it is still a very new sector in Ontario based on the economic conditions and available land considering the developing countries. In Ontario, recently three commercial aquaponics operations started their production. Aqua Greens in Toronto, established in 2013, provides "the most nutrient rich, locally grown organic greens and tilapia to grocery stores and restaurants". Their goal is to support local communities through eco-friendly sustainable aquaponic food production to strengthen the community economically, socially and environmentally. Green Relief, Canada's first and largest commercial aquaponics grower and licensed medical marijuana producer was started in February 2016.

2.5 Aquaponics: an innovative food production system and its importance

The definition of aquaponics according to the Oxford dictionary "A system of aquaculture in which the waste produced by farmed fish or other aquatic creatures supplies the nutrients for plants grown hydroponically, which in turn purify the water". Aquaponics offers a supportive and collaborative technique for producing fish and vegetables in locations and situations where it is difficult/impossible for soil-based agriculture and where water is scarce (Okemwa, 2015). The sustainability of aquaponics depends on the environmental, economic and social dynamics. The initial investment is high but is followed by low recurring costs. Environment-friendly aquaponics keeps the fish feces in the system and prevents pollution (FAO, 2014). Furthermore, aquaponics controls water uses and avoids the escape of fertilizers and insecticides, which makes food safer with respect to potential residues. In the social context, aquaponics positively contributes to improving quality of life by providing locally grown food while considering consumers' requirements and choices (Diver & Rinehart, 2010). Simultaneously, aquaponics incorporates social livelihood to secure food and incomes for landless urban dwellers. In developing countries, aquaponics can contribute to community/women's empowerment and emancipation for sustainable socio-economic growth (Azad et al., 2016). The current application of aquaponics is considered domestic/small scale aquaponics, semi-commercial and commercial aquaponics, educational/institutional, and humanitarian relief and food security interventions (FAO, 2015). It has been addressed by Canadian research that growing plants from organic fertilizer, fish wastes, in cold climates in greenhouses is considerably better than growing plants hydroponically using inorganic fertilizers (http://www.greenhousecanada.com). The NOA Fisheries, Whitby, Ontario has organized three

workshops on aquaponics within six months (February 16-18, June 27-29 and August 22-24). The participation was C$899/person and it had 50-60 participants in each course.

2.6 Aquaponics versus Conventional Farming

Aquaponics is a sustainable, eco-friendly food production system that offers healthy and local food (Okemwa, 2015). The produce from aquaponics is organic and able to operate in limited space in the urban area. Aquaponics is prescribed as a therapeutic, relaxing and fun activity with the option of producing one's own food (Laidlaw & Magee, 2014). More varieties of plants and fish are able to be combined in aquaponics systems as compared to conventional farming. Since aquaponics is an intensive farming system, the vegetables can produce 3-4 times the density and exhibit significantly faster growth (Tyson et al., 2011). In aquaponics, fish are produced without any antibiotics or hormones in a natural environment. The greatest advantage of aquaponics is that for the accumulation of water from the fish tank, plants are the main source of filtration which eliminates an enormous cost for the producers. Love et al. (2014) acknowledged that aquaponics is a revolutionary solution for many parts of the world, especially in the third world countries where the limitation of land, desert climates, drought situations, and other natural limitations, due to the system's limited water use and solar power.

2.7 Social and educational benefits of aquaponics

In many developing countries, rural poor communities are struggling for affordable healthy food and engaging in urban agriculture, thus strengthening their food security. De Bon et al. (2010) reported the prospects of aquaponics as a part of urban farming to minimize increasing food demand in the cities especially in the developing countries where agriculture is the main

employment sector. In developing countries, 65% of urban farmers are women, contributing to reduced gender inequality and greater social inclusion (Eigenbrod & Gruda, 2015; Orsini et al., 2013).

In many countries, aquaponics is being implemented in the school curriculums for educational purposes. Sustainable cultivation of plants as an urban hydroponic greenhouse on a rooftop is being taught in the Manhattans School for Children, in Manhattan, USA. Students are taking care of fish and performing water quality testing during the class to acquire hands on knowledge for the awareness of healthy food. They are taught resource management, biodiversity, and sustainability (Eigenbrod & Gruda, 2015; Specht et al., 2013). Tortorello (2010) estimated that in the USA that there was 800-1200 home aquaponic systems and 1000 school aquaponic systems. Nelson (2007) outlined a list in the Aquaponics Journal including Shrewsbury Elementary School (Pennsylvania), Canby High School (Oregon), Tunstall High School (Virginia) and some other successful educational aquaponics systems in the U.S. and North America (Hart et al., 2013). The success of this aquaponics education received coverage in newspapers, trade magazines, and communities. The average cost for an education in aquaponics is approximately UD$500.

2.8 Aquaponics for environmental sustainability and climate change

In agriculture, extreme weather conditions and climate change causes pests and diseases and are the main reason for losing harvest or yield (Eigenbrod & Gruda, 2015). Different authors projected that by 2100, the global mean temperature may rise by 2°C which may threaten the production of agricultural commodities (Eigenbrod & Gruda, 2015). On the other hand, agriculture is accused of environmental pollution due to the use of pesticides, insecticides,

chemicals, and fertilizers. Sustainable organic food products such as aquaponic-based foods are the remedy to avoid this environmental pollution. Germany, the Netherlands, Slovenia, etc. are promoting organic urban agriculture in order to maintain and enhance food production in urban areas (Eigenbrod & Gruda, 2015; de Bon et al., 2010). Aquaponics plays a vital role in producing a natural environment and makes the city greener. The ecological footprint of the cities' is controlled through recycling organic wastes and reducing energy consumption (de Zeeuw et al., 2000; Bohn & Viljoen, 2011). Moreover, urban food production systems minimize the logistics and storage costs, and control CO_2 emissions as well as prolong the shelf life of the produce. Kulak et al. (2013) reported that 20-30% of global greenhouse emissions come from agricultural food production systems. Since urban farming (aquaponics) is an indoor farming system, there are no effects from climate change such as pollution and extreme weather conditions and is environmentally-friendly with respect to carbon emissions (Specht, Siebert, Hartmann, Freisinger, Sawicka, Werner, Thomaier, Henckel, Walk, & Dierich, 2013).

2.9 Opportunities and challenges in aquaponics farming

Table – 1: SWOT analysis (Laidlaw & Magee, 2014; Klinger & Naylor, 2012; Okemwa, 2015)

Strengths: existing or potential resources or capability for aquaponics - increasing demand for aquaculture products - the sustainable and eco-friendly food production system - a wide range of aquaponic production suitable for urban areas - extremely water efficient and features a soilless environment - no need for any fertilizers or pesticides; a higher level of biosecurity and risk-free from contamination - organic production with high yield and the creation of very limited waste - aquaponics provides income and organic food and refreshment	**Weaknesses:** existing or potential internal major weakness of aquaponic food production - the initial investment is high compared with existing traditional farming systems - knowledge is required of fish and plant production - important to maintain the balance of fish and plants in the system and their growth - daily management is higher than in traditional farming - need to ensure the availability of fish fry, plant seeds, electricity etc. - higher energy costs
Opportunities: existing or potential issues in the external environment that might be advantageous - as an organic food, high demand in the local market - higher price than the imported or unknown produce - the worldwide increasing demand for fish protein over animal protein - positive contribution to waste management in urban areas - affordable food production system for all levels of people in the community	**Threats:** existing or potential threats in the external environment that might interfere with aquaponics systems - excessive urban farming may overwhelm the capacity of the supporting ecosystem - inappropriate system management may cause conflicts with neighbors and resource users - access to land and inputs may be interrupted owing to competition with the development plans - demand for fish and plants may decline because of negative media coverage caused by animal welfare, environmental issues, and public health concerns

The opportunities and challenges involved in innovative new technologies in aquaponics farming are reviewed here using a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis for individual urban aquaponics enterprises (Table – 1). These can integrate larger evaluation frameworks for a city's readiness or preparedness for sustainability (Laidlaw & Magee, 2014).

Aquaponics promotes a more sustainable food production system through the limited use of water, land, and energy. The production of both fish and vegetables needs only fish feed as a nutrient and ensures that most of the wastes that would normally be released from intensive fish culture are instead used to grow vegetables. Agricultural production may be severely affected due to lack of proper pollution control and insufficient wastewater management and lead to extensive fish kills, and health risks for consumers. To minimize wastewater treatment costs, aquaculture producers could extend their research on integrated waste water management.

2.10 Conceptual Framework

The conceptual framework of this paper aims to analyze the sub-sector of aquaculture and aquaponics in Ontario. In addition, this paper will analyze the social, environmental and economic factors that are necessary for food security. There is a major research gap existing with respect to knowing who is practicing aquaponic farming and where these facilities exist in Ontario. This paper examined recirculating aquaculture systems coupled with hydroponics to determine their use as a viable business model in an urban, peri-urban and rural context in Ontario. The method of analysis included a review of available literature and case studies of aquaponics as a commercial application for sustainable food production.

Sustainability of Aquaponics

- **Social benefits**
- **Environmental benefits**
- **Economic benefits**

Figure – 2: A simple Conceptual Framework for sustainability of aquaponics (Source: author)

Summary

The earth has depleted soil, mineral and water resources and is running out of inexpensive energy sources (Silcos, 2013). The modern technology of recirculating aquaponic systems can produce both protein and vegetables while limiting water use and eliminating the use of soil and minimizing the use of other natural resources. The advantage of this farming system is that it can be located anywhere, including regions with little water and on limited space either indoors or outdoors. The wastes from the fish tank can be eliminated and turned into value-added products which results in a profitable business model. This can increase the community's resiliency against increasing food costs brought on by failing farmlands and transportation costs, at the same time, providing economic development benefits to the community.

Chapter 3: Case studies

3.1 Introduction

In this chapter, two case studies were analyzed: 1) Green Relief, naturally-grown, better-than-organic medical cannabis; and 2) Aqua Greens, aquaponics business serving Ontario's restaurants. The descriptions of both cases include construction of the facility, system operation, maintenance, production, and marketing plan. In addition, social, environmental, and economic benefits to evaluate the sustainability of both cases are discussed. Significant differences between the two cases including construction, operation, and maintenance are highlighted.

3.2 Case study – 1: Green Relief Case Study

CASE STUDY REDACTED IN FINAL COPY DUE TO CONFIDENTIALITY. REQUESTED BY GRADUATE COMMITTEE & GREEN RELIEF.

3.3 Case study – 2: Aqua Greens

Craig Petten and Pablo Alvarez have developed Aqua Greens, a commercial scale innovative aquaponics system in a 3,000 square foot facility in an industrial park, Mississauga, Ontario. The production capacity is able to grow 12,000 plants and keep 5,000 fish. Their mission is to enhance local communities by providing fresh and local vegetable products while at the same time protecting natural resources and ensuring sustainable environmental impacts. Aqua Greens is a combined process of hydroponics and aquaculture in which plants, fish, and light work together to create a nutrient-rich system similar to an earthen pond. In this enclosed

recirculation system, the fish feed the plants and the plants clean and filter the water which is sent back to the fish. At Aqua Greens, fish are fed in the morning and excrete ammonia through gills and waste, which starts the nitrification process. The plant roots that pass through the Styrofoam absorb the nutrients. The aquaponic system provides 12 nutrients out of 15 needed to grow plants; calcium, potassium, and iron are added for faster growth than the soil-based system. In the aquaponics system fish is the engine of the system.

Aqua Greens system construction and maintenance:

At Aqua Greens, the key component in the recycling aquaculture system is the removal of the harmful waste products and uneaten food from the rearing tanks while continuing to recycle the water. The practice of this technique utilizes the fish effluents in the growing of plants in a hydroponic setting. The wasted uneaten food that collects at the bottom of the rearing tanks is removed by PVC pipe to a clarifier or saddler. The clarifier or saddler is where the anaerobic mineralization of the wasted and uneaten food occurs. Over the time, the waste material collected in the clarifier begins the breakdown and releases nutrients to the water. Trace materials such as iron may have to be added to supplement the plants' nutritional needs. This mineral rich water then moves through the biofilter. A bio-filter allows for the natural biological process called nitrification to occur. Through the breakdown wastes, a large amount of ammonia is released into the water. The natural bacteria present in the water use the oxygen in an aerobic process to efficiently convert the Ammonia to Nitrite and then to Nitrate. The bio media in the bio-filter expedites the process by allowing the bacteria to colonize in an area with direct water temperature, pH and dissolved oxygen level. This nitrate-rich water then moves to the plant grow bed.

The plant's roots are immersed in water, absorbing the rich nutrients while simultaneously filtering out the nitrogenous compounds that are toxic to the fish. Deepwater raft aquaponics uses Styrofoam mats to secure the plants in the trap of water. The seedlings are placed in a net pot with the planting medium like coco pit, the material from the outermost shell of the coconut. Coco pit stimulates and protects root growth and contains no minerals. The plants are grown to maturity in that pot or can be removed from the pot after a couple of weeks and placed in a different floating mat to maximize the space in the grow bed. The aquaculture water loads the grow bed containing the plant and growing medium. This type of system is known as recirculating aquaponics or closed-loop aquaponics.

Water is only half the equation when it comes to planting growth; the other of course is light. Lighting depends on the location of the aquaponics system. At Aqua Greens, artificial lights are used for maintaining room temperature and light intensity for growth. There are several types of lights that are used depending on the application. A greenhouse provides economic advantages by reducing the amount of artificial light required.

Like selecting the species of fish, choosing what plants to grow is a crucial decision that affects infrastructure and business planning. Aqua Greens produces lettuce, chives, basil, arugula etc. in the aquaponics system and any common garden vegetable that can be grown. It is important to make careful consideration to plant selection because, in an aquaponics operation, the plant side tends to generate more income. Aqua Greens has surveyed the market demand and chose plants to generate the largest profit margin.

As the water moves through the grow bed, the plant's pull-out nutrients. The filtered water flows from the bed to the lowest point in the system called a sump. From there water is

pumped back into the rearing tanks and the recycling continues. Some micronutrients, such as iron and magnesium are added to the system to ensure plant health.

The greatest advantage of the Aqua Greens indoor aquaponics system is the availability of year-round local produce for the restaurants, which is appreciated by the local community. Aqua Greens produces basil, and other green vegetables to supply various restaurants including Buca, Hockley Valley Resort, Cibo and Maple Leaf Sports and Entertainment Catering. Alvarez reported "It's amazing dealing with chefs and restaurants; they love the fact we can deliver 365 days a year. In the middle of winter in January, it's -40°C, we're delivering organic local greens". Tilapia can naturally tolerate crowding, a greater range of water temperature and pH levels; these are the advantages of choosing tilapia for an aquaponics system. Considering these characteristics, tilapia is called aquatic chicken. Generally, two types of tilapia, Nile, and Red are standard crops and are found to be 0.51 lbs/gal and 0.59 lbs/gal respectively. In Aqua Greens aquaponics, 95% of water is reused in the recirculation system which uses 90% less water than the conventional aquaculture system.

Summary

These two case studies on aquaponics address pre-existing issues concerning agricultural development in Ontario. First, they provide motivational information to promote an innovative farming system that is less labor intensive, more affordable, and with higher productivity than the conventional farming systems. Second, aquaponics farming offers environmentally sustainable alternatives to current farming practices, providing beneficial healthy food, contributing to both a domestic market and earning foreign exchange. Third, individuals have the opportunity to grow required food than existing alternatives. All of these advantages support the

goal of sustainable food production systems for food security and are pursued through the aquaponic food production system. After analyzing these case studies, it can be concluded that aquaponics has become a viable alternative for food security and sustainable food production in Ontario.

Chapter 4: Discussion, Conclusions, and Recommendations

4.1 Introduction

This chapter discusses major findings from the case studies and describes how aquaponics contributes towards the sustainability of food security for the community. In addition, recommendations for further research and concluding remarks are presented. In the discussion, sustainable fish feed and energy management, stakeholder's involvement and system management were partially explained.

4.2 Discussion

For thousands of years, fish have been a vital food source for human consumption and the demand for fish consumption in modern society has increased significantly. In order to feed a burgeoning population, a radical rethinking of production techniques and dietary needs is required. Aquaponics has the potential of being the perfect "People, Planet, and Profit" triple bottom line business, by providing healthy food to communities, reducing the ecological footprint of agriculture, and contributing to the strength and economic growth of communities. Globally, at least 43 countries on every continent are practicing aquaponic farming (Love et al., 2014). Most of the aquaponic systems are designed by the owners and built on his/her property in the greenhouse or indoors, even in abandoned warehouses. Aquaponics is usually practiced for commercial producers, hobbyists, and educational purposes.

In 1996, the World Food Summit concluded the conceptual structure in achieving food security: access, availability, stability, and utilization (Dustin, 2014). The concern over food security over the last few decades are integrated into these four-key criteria and integrate the concern of food security and furthermore describes the situation from the social environmental

perspective (Gibson, 2014; Dustin, 2014). Carr (2006) indicated that social, environmental, and economic benefits of the communities should be achieved from sustainable food production systems.

When comparing conventional agricultural systems with the innovative aquaponic system, very clearly defined financial feasibility, sustainability, healthiness, social and environmental factors are taken into account. Aquaponics reduces the environmental footprint in crop production and allows the production of fish and plants in locations that are not typically associated with farming, from a windowless basement to a room modeled urban townhouse to a retrofitted old factory building. If there is access to electricity and water, fish and crops can be raised in these indoor eco-friendly symbiotic environments. However, with the ability to raise fish and grow plants indoors year-round, a major issue to consider is the energy costs associated with heating and air conditioning. Making sure the building is well insulated will cut down these costs. Water temperature needs to be maintained for the health of the fish and room temperature needs to be regulated for the plant's growth. Each aquaponics system can be designed to maximize the use of available space. A room with a high ceiling, like Aqua Greens', can allow for the stacking of grow beds. This requires more plumbing but the investment produces greater plant production. Utilizing natural light from existing windows in an old factory building can also help by reducing artificial lighting costs. With careful planning and caretaking, aquaponics can not only be an eco-friendly sustainable food production system but also a profitable business with significant growth potential.

In aquaponic operations, fish feed and energy are the vital inputs after installing a farm, and fish meal and oil are the major ingredients of the fish feed. Fish meal is getting expensive while sustainable fisheries management prioritizing to maintain natural stock, such as small fish.

However, for small producers, hobbyists, and educational projects that are aiming to reduce the cost of feed in their operations through natural feed supplementation, these efforts do require effort, time and expense. Fish nutritionists are researching alternate protein sources such as plant protein to minimize the cost of fish feed. Dr. Dominique Bureau, Fish Nutrition Laboratory, University of Guelph has conducted diverse research on supplementation using soybean meal, canola meal, corn meal as alternate sources. To evaluate the financial prospect of aquaponics farming energy or food prices, climate change, and the local market needs to be considered. Some other sustainability issues with the aquaponics business model in addition to the fish feed and energy issues are – water saving and recycling, intensive food growing on small lots, growing vegetables and fish, the ability to place the system anywhere, and year-round production regardless of climate.

The five key water quality parameters for aquaponics: dissolved oxygen, pH, water temperature, total nitrogen concentrations, and hardness are used to maintain the optimal water quality for fish, plants, and bacteria.

REDACTED (1 sentence)

This table - 2 highlights significant factors that appear to play a role in the sustainable establishment of Green relief and Aqua green.

Table – 2: Comparative study of two cases (Green relief and Aqua green)

Category	**Factors**	**Green relief***	**Aqua green**
Economic	Market outlets		Own delivery only to the local restaurants
	Market research		Look for only local consumers e.g. restaurants
	Additional revenue streams		No. Although experimenting for new crops.
	Independently Economically Sustainable based on Aquaponics production output		Yes, but very limited effort
	Business and governance model		For profit and business only
Social	Community support		Basic. Although forms part of organisation with strong community support. No capacity to support volunteers. Limited government support.
	Community engagement		Basic. Offers preliminary aquaponics tour at the site. No government engagement at any level.
Environmental	Operating environment		Indoor system Moderately maintains

Technical	System produce		Arugula, Basil, Lemon basil, lime basil, Opal basil, Thai basil, Dandelion, Mastered greens
	Energy		Limited uses of energy
	Aquaponics system efficiency		Not very efficient system and still needing ongoing support from aquaponics expert. Providing modest income.
	Preliminary Aquaponics Research Conducted		Limited research.
	Ongoing aquaponics research		Monitoring inputs and outputs over a year.

*REDACTED (Source – author)

There are many strategies that aquaponics systems can employ to help the community, but they do not necessarily help the economic sustainability of the organizations operating the systems. Aquaponics growers can work with the community to improve urban farm education, provide training programs, create business idea development, and can help to establish community gardens. These strategies can improve communities' good-will and communication, and in addition, can prove to be a great marketing opportunity for selling produce.

In addition, aquaponics encourages different stakeholders such as smallholders and motivates people to take training courses on aquaponic farming. NOA Fisheries in Whitby, Ontario, is organizing workshops and consultancy on aquaponic farming 3 – 4 times per year to support this growing industry.

4.3 Conclusions

Aquaponics is a sustainable agricultural production system that makes diverse contributions. It also helps to solve water scarcity and soil depletion and helps to increase the availability of desired food production in urban and rural areas. In aquaponics, energy consumption is much less than in conventional farming systems and promoting the environmentally sustainable alternative farming system. It is important to create more entrepreneurs in aquaponic farming to move this method forward as playing a key role in sustainable food security and economic development. In addition, to minimize food prices, to get fresh organic food, and transportation costs, aquaponics is ideal for urban farming.

This paper discusses the sustainability of commercial aquaponics organization for the community and their social and economic development. These case studies review technical and business management skills combined with enduring leadership. Equally important is that these stakeholders remain involved and are prepared to cooperate with each other in the face of technical and operational challenges. This is often the case in successful social enterprises where, despite the need to be economically viable, the driving energy for the project comes from the desire to bring about social change and to stimulate a transition towards a system that measures wealth and health and sustainability in other than purely financial terms. In conclusion, aquaponics farming is a very prospective sustainable food production system in Ontario.

4.4 Recommendations

Certainly, aquaponics is an ingenious way of growing both fish and plants. Aquaponics is a thriving system that will not only increase and diversify the farm's production but will also generate much attention for growing non-profit organizations. The viability of integrating aquaponics into systems of food security depends on the commitment level of the organization,

dedicated staff, and creative planning. Further research is required to reduce energy costs, formulate feeding regimes for fish, deal with fish mortality control and provide for close monitoring of the system. In addition, research can help identify ethnic vegetables for multicultural communities and more medicinal plants to contribute towards the social benefits of aquaponic farming. In aquaponics, fish might need to be fed formulated diets rather than the existing commercial ones based on plant residue accumulation in the recirculation system. In many situations, greater supervision is needed for aquaponic operations than the traditional farming systems, especially for fish health. A video surveillance or/and an innovative mobile app could be an option to track the system conveniently in any situation.

An aquaponic operation may require inputs from the government and community such as donations, grants, and volunteers. Several activities such as workshops, tours, merchandising, fundraising, consulting, workforce training, partnerships with universities and education programs with local schools are the best options to increase revenue. The government can provide low-interest loans to set up new facilities to encourage entrepreneurs to produce organic food. For the future analysis of aquaponic systems, there is a need to conduct more research on other medicinal plants besides medical marijuana that can provide greater health benefits from natural rather than artificial sources.

4.5 Concluding Remarks

Aquaponics shows great potential for the prospect of benefiting urban and rural communities by providing food, employment, entrepreneurship, community cooperation and finally the livelihood of the earth. Aquaponics has the potential to address food security through the local production and consumption of healthy, chemical-free food and environmentally

sustainable methods of food production. Therefore, aquaponic farming is more than just a method of food production; it is a way of inspiring entrepreneurs, nourishing communities, and creating a better sustainable future.

References:

Azad, K. N., Salam, M. A., & Azad, K. N. (2016). Aquaponics in Bangladesh: current status and future prospects. Journal of Bioscience and Agriculture Research, 07(02), 669–677.

Bohn, K., Viljoen, A. (2011) The edible city: envisioning the continuous productive urban landscape. Field J 4(1):149–161

Blidariu, F., & Grozea, A. (2011). Increasing the economical efficiency and sustainability of indoor fish farming by means of aquaponics-review. Scientific Papers Animal Science and Biotechnologies, 44(2), 1-8.

Buzby, K. M., & Lin, L. S. (2014). Scaling aquaponic systems: Balancing plant uptake with the fish output. Aquacultural Engineering, 63, 39–44.

Carr, E. (2006). Postmodern Conceptualizations, Modernists Application: Rethinking the Role of Society in Food Security, Food Policy 31, 2006.

Connolly, K., & Trebic, T. (2010). Optimization of a Backyard Aquaponic Food Production System, 1–74.

Cunningham, B. (2015). A Study of Aquaponic Systems.

De Bon, H., Parrot, L., Moustier, P. (2010) Sustainable urban agriculture in developing countries. A review. Agron Sustain Dev 30:21–32.

de Zeeuw, H., Guendel, S., Waibel, H. (2000) The integration of agriculture in urban policies. In: Bakker N, Dubbeling M, Gündel S, Sabel- Koschella U, de Zeeuw H (eds) Growing cities. Growing Food. Dtsch Stift int Entw, Feldafing, pp 161–180.

DFO. (2012). Aquaculture in Canada 2012: A Report on Aquaculture Sustainability. Fisheries and Oceans Canada.

Diver, S., & Rinehart, L. (2010). Aquaponics — Integration of Hydroponics with Aquaculture. Water, 28.

Dudley, D. H (2017). Aquaponics: how to do everything from backyard setup to profitable business,

Dustin F. (2014). Food Security and Small-Scale Aquaponics: a Case Study on the Northern Mariana Island of Rota, (December).

Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities. A review. Agronomy for Sustainable Development, 35(2), 483-498.

FAO. (2002). The State of World Fisheries and Aquaculture.

FAO. (2014). The State of World Fisheries and Aquaculture.

FAO. (2014). The State of World Fisheries and Aquaculture.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M. (2011). Solutions for a cultivated planet. Nature 478:337–342

Forchino, A. A., Lourguioui, H., Brigolin, D., & Pastres, R. (2017). Aquaponics and Sustainability: The comparison of two different aquaponic techniques using the Life Cycle Assessment (LCA). Aquacultural Engineering, 77, 80-88.

Gibson, M. (2014). The Feeding of Nations: Redefining Food Security for the 21st Century. CRC Press.

Goodman, E. R. (2011). Aquaponics: Community and economic development, 1–100.

Graber, A., & Junge, R. (2009). Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. Desalination, 246(1-3), 147–156.

Graham, L. J. (2003). Aquaponics in Alberta: An environmental industry scan. Evaluation and Development of Aquaponics Production and Product Market Capabilities in Alberta, Initiatives Fund Final Report, Project #679056201, 1–24.

Hamilton, A.J., Burry. K, Mok H-F, Barker F, Grove JR, Williamson VG (2013) Give peas a chance? Urban agriculture in developing coun- tries. A review. Agron Sustain Dev 34:45–73.

Hart, E. R., Webb, J. B., & Danylchuk, A. J. (2013). Implementation of aquaponics in education: An assessment of challenges and solutions, 24(4), 460–480.

Hoffman, Ulrich. (2013). Agriculture At the CrossRoads: Assuring Food Security in Developing Countries Under the Challenges of Global Warming. UNCTAD, 2-8. <http://unctad.org/en/PublicationsLibrary/ditcted2012d3_en.pdf>

Kazakevich, M. (2013). Commercial Urban Farm Models for Guelph, Ontario (Doctoral dissertation).

Klinger, D. and Naylor, R. (2012). Searching for Solutions in Aquaculture: Charting a Sustainable Course, Annual Review of Environmental. Resources., 37: 247–76.

Klerkx, A., Leeuwis, Cees, L. H. (2009). Strengthening Agricultural Innovation Capacity: Are Innovation Brokers the Answer? Working Pa(31), 1–47.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. Agricultural Systems, 103(6), 390–400.

Kortright, R., Wakefield, S. (2011) Edible backyards: a qualitative study of household food growing and its contributions to food security. Agric Hum Values 28:39–53.

Kulak, M., Graves, A., Chatterton, J. (2013) Reducing greenhouse gas emissions with urban agriculture: a LifeCycle assessment perspective. Landsc Urban Plan 111:68–78.

Laidlaw, J. (2013). From Innovation To Sustainability: Surviving Five.

Laidlaw, J., & Magee, L. (2014). Towards urban food sovereignty: the trials and tribulations of community-based aquaponics enterprises in Milwaukee and Melbourne. Local Environment, 9839(November), 1–18.

Love, D. C., Fry, J. P., Genello, L., Hill, E. S., Frederick, J. A., Li, X., & Semmens, K. (2014). An international survey of aquaponics practitioners. PloS one, 9(7), e102662.

Lovell, S.T. (2010) Multifunctional urban agriculture for Sustainable land use planning in the United States. Sustainability 2:2499–2522.

Maxim, L., Spangenberg, J. H., & O'Connor, M. (2009). An analysis of risks for biodiversity under the DPSIR framework. Ecological Economics, 69(1), 12-23.

McGuire, T. M., & Popken, G. A. (2015). Comparative Analysis of Aquaponic Grow Beds.

Menon, R., Sahana, G. V., Shruthi, V., & Suganya, R. (2013). Small Scale Aquaponic System.

Moccia, R., Bevan, D., & Osuchowski, K. (2010). Seasonal Temperature Profiles at Ontario Cage Trout Farms and Management Implications.

Moccia, R.D., and D.J. Bevan. (2009). Aquastats: Ontario Aquacultural Production in 2007. University of Guelph, Aquaculture Centre Publication, 09-001.

Moccia, R. D., and Hynes, J. (1998). Sustainability of Ontario's Aquaculture Industry: 1998 and Beyond. Canadian Aquaculture Directory, Contact Canada. Fred Haynes Publ., Georgetown, Ontario, Canada, 29-31.

Moccia, R. D., and Reid, G. K. (2007). Aquaculture sustainability: developing concepts of a decision support tool for licensing freshwater cage aquaculture in Ontario. AAC Special Publication, (12), 106-114.

Moccia, R. D., and Bevan, D. J. (2007). Aquastats: Ontario aquaculture production in 2006. Order, (07-002).

Neher, D. (1992). Ecological Sustainability in Agricultural Systems: Definition and Measurement. Journal of Sustainable Agriculture, Vol 2. (3), pp.51-61.

Nelson, R. L. (2007). 10 great examples of aquaponics in education. Aquaponics Journal, 3(46):18-21.

Okemwa, E. (2015). Challenges and Opportunities to Sustainability in Aquaponic and Hydroponics Systems. National Commission for Science, Technology and Innovation (NACOSTI). Kenya.

Orsini, F., Kahane, R., Nono-Womdim, R., Gianquinto, G. (2013) Urban agriculture in the developing world: a review. Agron Sustain Dev 33:695–720.

Pant, L. P. (2014). Critical systems of learning and innovation competence for addressing complexity in transformations to agricultural sustainability. Agroecology and Sustainable Food Systems, 38(March), 336–365.

Rakocy, J. (2007). Ten guidelines for aquaponic systems. Aquaponics J, 1, 14-17.

Rakocy, J. E. (2012). Aquaponics: integrating fish and plant culture. Aquaculture production systems, 1, 343-386.

Savidov, N. A., Hutchings, E., & Rakocy, J. E. (2007). Fish and plant production in a recirculating aquaponic system: A new approach to sustainable agriculture in Canada. Acta Horticulturae, 742, 209–222.

Schut, M., Rodenburg, J., Klerkx, L., Kayeke, J., van Ast, A., & Bastiaans, L. (2015). RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part II). Integrated analysis of parasitic weed problems in rice in Tanzania. Agricultural Systems, 132, 12-24.

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L. C., Raboanarielina, C. M., & Bastiaans, L. (2015). RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agricultural Systems, 132, 1-11.

Silcox, D. (2013). "Aquaponics as a Sustainable Urban Business Model", A Thesis published under Central Connecticut State University, Connecticut.

Specht, K., Siebert, R., Hartmann, I., Freisinger, U.B., Sawicka, M., Werner, A., Thomaier, S., Henckel, D., Walk, H., Dierich, A. (2013) Urban agricul- ture of the future: an overview of sustainability aspects of food production in and on buildings. Agric Hum Values Springer Science+Business Media Dordrecht.

Summerfelt, S. and Christianson, L. (2014). World Aquaculture, Canada.

Systems, R. A., Unit, R. A., & Unit, S. H. (n.d.). Sustainable Aquaculture development through the smart use of water: small scale aquaponics in Ethiopia water: small scale aquaponics in Ethiopia Project Objective sustainable Aquaculture development through the smart use of Project Outputs: Aquaponics.

Tortorello M (2010). The Spotless Garden. The New York Times. New York.

Tyson, R. V., Treadwel, D. D., & Simonne, E. H. (2011). Opportunities and challenges for sustainability in aquaponic systems. HortTechnology, 21(1), 1–13.

http://www.omafra.gov.on.ca/english/livestock/urbanagbib/welcome.htm retrieved on July 12 2017

http://www.greenhousecanada.com/inputs/crop-culture/the-future-of-aquaponics-looks-bright-at-brooks-965 retrieved on July 12, 2017

https://www.ontario.ca/foodland/food/fish retrieved on July 12, 2017

Appendix – 1: Commercial aquaponics in Ontario:

Initiative	Location	Brief Discussion
1. Green Relief	REDACTED	REDACTED
2. FreshCityFarms	53 Samor Rd, North York, ON M6A 1J2 Toronto, Ontario	A city farm and are proud to work with some of Ontario's finest growers. From sourcing from organic farms to packing in reusable bags to delivering with electric bikes, our operations respect both people and planet. We are a Certified B-Corp and have been featured in several documentaries for our pioneering work in farming the city (Collected from the home page).
3. Ripple Farms	Toronto, ON Phone: (647) 921-7496	Ripple Farms has brought Canada's First Urban Farming Unit to The Evergreen Brickworks in Toronto. In business, Ripple operates as a Social Enterprise and is dedicated to putting people before profits. Our mission is to provide customers with nutrient-rich, locally produced food. Their purpose is to reconnect urban populations with food by engaging people through hands-on workshops and educational material. Our Aim is to tackle food security one meal at a time. With our systems, there is no longer a need to have to produce shipped thousands of kilometers when we can produce it right here on Canadian soil (Collected from the home page).

4. The Mississauga Food Bank Aquaponics	3121 Universal Drive Mississauga ON L4X 2E2 phone 905.270.5589 fax 905.270.4076	Mississauga opens Canada's first aquaponic food bank farm. The farm produces 40 heads of lettuce a week. Fish will be harvested every six months, which will produce about 57 kilograms of fish every year. Hatch said this is equal to approximately 10,000 servings of fish and lettuce (Collected from the home page).
5. Aqua Greens	2798 Thamesgate Drive, Unit - 7, Mississauga, L4T 4E8	Aqua Greens is dedicated to providing the most nutrient rich, locally grown organic greens and tilapia to grocery stores and restaurants in the city of Toronto. We are passionate about strengthening local communities through the celebration and awareness of aquaponic food production in ways that are economical, socially and environmentally responsible.
6. Niagara Aquaponic Produce	Business Type: Grower/Producer, School Supplier/Vendor, Seller Business Address: 30 Barnaby Drive, St. Catharines, ON L2S 3C8, Canada Phone:(289) 968-4238 Cell:(289) 968-4238	In Niagara to offer consumer customized, signature sprout blends, wheat grass and a full line of chemical-free heirloom vegetables using an aquaponic greenhouse system. All produce is entirely GMO-free and grown without the use of synthetic fertilizers, pesticides, herbicides or fungicides and using 100% environmentally responsible farming methods. Heirloom and aquaponic produce will be available and market ready by Fall 2014. 100% family owned and operated businesses located in beautiful St. Catharines, ON, Canada and servicing the entire Niagara Region from Welland, Fonthill, Niagara Falls, Wainfleet, Grimsby, Port Colborne, etc.

7. WATERFARMERS AQUAPONICS	CREDITVIEW RD, MISSISSAUGA, ON (877) 873-9307	Providing turnkey aquaponics solutions around the world, WaterFarmers is Toronto's premier professional aquaponic consulting group. Are committed to delivering technology-based food security solutions for our clients, and driven by a belief in the value of hyper-local whole foods. With active projects in Canada, the Middle East, and Asia, ranging from hobby to commercial scale, WaterFarmers is an industry leader in aquaponic system design.
8. A&M Aquaponics Inc.	Stoney Creek Canada Ontario	Organic produce still show residue of pesticides
9. ST. DAVIDS HYDROPONICS LTD.	822 Concession 7, RR #4, Niagara-on-the-Lake, ON, Canada L0S 1J0	In business since 1985 and have grown to over 70 acres of greenhouses, still, believe in doing things slowly and correctly. Greenhouses allow to control the environment and provide plants with ideal growing conditions from the temperature to humidity and sunlight. Growers have over 100 years of combined experience gained from training around the world. Their attention to detail and genuine passion for what they do is seen in the world-class plants they produce. Their carbon footprint should be as close to zero as possible and in the summer months, it is, even uses water gathered from the roofs of our greenhouses to water our plants.