Spring 2018

Sustainable agriculture: Integration of aquaponics at Punta Leona Hotel and Club in Costa Rica

Cailin Sierra Dyer  
*James Madison University*

Paris Riley Smith  
*James Madison University*

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Sustainable Agriculture: Integration of Aquaponics at Punta Leona Hotel and Club in Costa Rica

An Honors College Project Presented to the Faculty of the Undergraduate College of Integrated Science and Engineering

James Madison University

In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

by Cailin S. Dyer and Paris R. Smith

May 2018

Accepted by the faculty of the College of Integrated Science and Engineering, James Madison University, in partial fulfillment of the requirements for the Honors College.

FACULTY COMMITTEE: HONORS COLLEGE APPROVAL:

Project Advisor: Shannon N. Conley, Ph.D. Bradley R. Newcomer, Ph.D.,
Associate Professor, Integrated Science and Technology Dean, Honors College

Project Advisor: Karim Altaii, Ph.D.
Professor, Integrated Science and Technology

Reader: Wayne S. Teel, Ph.D.
Professor, Integrated Science and Technology

Reader: Christy M. Bradburn, M.A.
Adjunct Faculty, Geographic Science

PUBLIC PRESENTATION
This work is accepted for presentation, in full, at the Integrated Science and Technology Senior Symposium on April 20, 2018.
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Finally, we would like to thank the departments at James Madison University that provided the funding to give us the opportunity to publically present our research. Thank you to the College of Integrated Science and Engineering for funding our travels and engagement at the Dimensions of Political Ecology Conference at University of Kentucky in February 2018. Also, thank you to the Honors College, specifically Jared Diener and Dr. Philip Frana, for giving us the opportunity to share our research at the Southern Regional Honors Council in Arlington, Virginia in April 2018.
Abstract

Sustainable agriculture is becoming an increasingly important method of food production. As human populations continue to grow, attendant food demand has been increasingly met via agribusiness, including monoculture crop production and factory farming. As is well documented, the rise of agribusiness has led to resource degradation and declining stocks on which “sustainable agriculture” relies. This paper describes a local attempt to re-establish “sustainable agriculture” through the development of an aquaculture system that mimics a naturally occurring cycle that integrates fish and plants. The system was constructed over a three-week period in Punta Leona, Costa Rica. First, the ground was cleared and leveled and the supporting legs were installed and cemented. The holes for the fish tanks were dug out of the ground and the fiberglass tanks were installed in the holes. Once the legs were completed, the separately constructed media bed was set up on the supporting legs, lined, and filled with lava rock. The system was completed by installing the piping system and filling the system with water, plants, and fish. Punta Leona Hotel has established a series of goals to achieve within the next decade to qualify as an Eco-tourist destination. The purpose of installing an aquaponics system at the resort was twofold: 1) to produce fresh greens and fish on-site for the hotel’s restaurant, and 2) to serve as an educational tool about environmental sustainability for their residents. This paper analyzes the ecological benefits and costs of the system, aside from the construction of the system. More specifically, the paper analyzes the food miles and life cycle of the food currently served at Punta Leona Hotel and Club and the change in food miles and food life cycle with the implementation of the aquaponics system.
Introduction

1. Environmental Issues

1.1. Resource Consumption

The United Nations calculated that there are over 7 billion people currently living on Earth. This is a rapid growth rate from the 1 billion people that were living on the Earth 200 years ago. Between 1900 and 2000 the world’s population increased from 1.5 to 6.1 billion people. This is three times greater than the entire previous history of human existence. The current human population growth on Earth is exponential and this growth fuels the use of more resources than have ever been needed to sustain the population before. Large scale agricultural practices are a major contributor of greenhouse gases to the atmosphere every year. In addition to greenhouse gas emissions, the agricultural sector contributes to land degradation, deforestation, and a number of other practices that reduce natural carbon sinks in the environment. In addition to the human population increasing rapidly the standard of living has also continued to increase, requiring more resources per person. The Human Development Index is a way to represent standard of living, life span, and education. The world Human Development Index score can range from 0 to 1 and rose from .56 in 1980 to .70 in 2013 in the United States and continues to rise each year. This rise shows the gradual increase in standard of living for the world’s population as the world’s population exponentially grows. Every year more food is required to feed the population, more energy is created and used, and the transportation need for people, raw materials, and goods increases. The rise of both population and standard of living has caused a drastic amount of natural and manmade resources to be used, consumed, disposed of, and wasted each year. The exploitation of the Earth and its natural resources to meet these ever rising demands in
largely unsustainable manners has contributed to climate change through the emission of greenhouse gases and unsustainable land and resource use.

1.2 Why Sustainable Agriculture?

The accepted definition for sustainable agriculture is "an integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological systems and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole." The farming system around the world is also largely unsustainable and this creates a need for local, sustainable farming systems like an aquaponics system that provides local food. One major issue in the U.S. is over consumption of red meats. The Standard American Diet (SAD) that consists of mostly meat will emit around 3.3 tons of CO$_2$ per person each year, while a diet that consists of only plants will emit less than half of that at 1.5 tons of CO$_2$ per person a year. A diet that consists of no beef, but still contains chicken, fish, and pork, falls in the middle with 1.9 tons of CO$_2$ per person each year. Mono-cropping is also an issue in the current agricultural system. Forests are burned and cut down to make space for more mono-cropping lands, which leads to an increase in carbon dioxide production and a reduction in carbon sinks provided by trees and vegetation. This leads to a lack of nutrients in the ground and a lack of biodiversity in many crops. The agricultural industry uses large amounts of water for irrigation and livestock as well as to process the crops and livestock after harvest. Pesticides and fertilizers pose another environmental threat. These chemicals make their way into soil and waterways and
harm the wildlife and ecosystems that they enter. Since most food is not grown locally, unsustainable transportation is used to ship foods far distances, even across country lines. Local food systems and eating seasonal foods can help make food systems more sustainable and able to run long term without harming the Earth as drastically as current, conventional agriculture.

2. Stakeholders

2.1. Punta Leona Hotel and Club, Costa Rica

One of the main, small-scale stakeholders is Punta Leona Resort and Club, as they are providing the primary source of funding for the aquaponics system and will reap the benefits of the system. The resort has published a list of goals set for 2020 to improve the overall visitor experience. For one goal, they aim to promote sustainability, both environmentally and culturally. They are also striving to develop a reputation as an organization with a high sense of social responsibility in addition to being a quality employer. Of the goals set by the resort, these two goals pertain to the installation of the aquaponics system. By providing sustainably sourced, organic food for their customers, the resort will be able to claim that they are taking on their social responsibility to participate in sustainable practices.

In addition to the goals set by Punta Leona Hotel and Club, there are number of areas that Punta Leona Hotel and Club has already implemented sustainable practices. The resort currently monitors and protects natural resources and species. The aquaponics system will improve their preservation of the marine wetland by collecting rainwater and preventing excess runoff that enters the ocean from the resort. The resort prides itself on
sustainable waste disposal. They have avenues for responsibly disposing of aluminum, plastic, cardboard, paper, electronic waste, batteries, fluorescents, glass, cartridges, empty toners, cooking oil, and motor oil. In addition, organic waste from their restaurants is taken to a local pig farm. Each of these disposal methods contribute to sustainable practices. The resort has also integrated numerous environmental education opportunities in the guests’ experience. Visitors can be trained on the marine wetland, take part in guided walks and painting contests, all to further understand the human impact on the environment, specific to Costa Rica. The aquaponics system will provide another educational tool for visitors to witness a functioning version of sustainable urban agriculture. Punta Leona also has an active wastewater treatment system on site. The resort properly treats wastewater to later be used as irrigation for the gardens.

In recognition of the sustainable practices set by the resort, Punta Leona has received various awards and accreditation for their efforts in sustainability. Blue Flag Ecological Program has recognized Punta Leona for its community, wildlife refuge, and actions to tackle climate change. Punta Leona has also received four out of the five levels of the Certificate for Sustainable Tourism granted by the Costa Rican Institute of Tourism. This certificate ensures that recipients are sustainably managing natural, cultural, and social resources. Finally, the resort has been recognized for its sustainable restaurant practices and the maintenance of their water treatment facility. The aquaponics system will allow the resort to further excel in areas where they have already received recognition for sustainable practices.

2.2. James Madison University in Harrisonburg, VA
The Integrated Science and Technology Department at James Madison University is an important stakeholder in this project. The department strives to provide students with hands-on research opportunities and produce graduates who are adaptable problem solvers, knowledgeable, socially aware and engaged, intellectually creative, and flexible. The aquaponics project parallels the vision of the Integrated Science and Technology Department by allowing the team of students to apply technical sciences in a social context while working as an environmental contractor. Integrated Science and Technology graduates are expected to be able to examine a problem and assemble the tools and knowledge needed to solve it. The department strives to give students the ability to analyze science and technology within broader global, political, economic and social contexts. The implementation of a local aquaculture system in Costa Rica gives students the opportunity to apply the skills gained throughout their time in the Integrated Science and Technology Department. The project combines a multitude of economic, political, environmental, and cultural factors that must be balanced and analyzed throughout the planning and implementation of the system. Without considering and weighing these factors, the project cannot succeed.

3. Public Policy

Sustainable agriculture is a subset of sustainable development which has a primary focus in economic development as opposed to economic growth. Sustainable agriculture strives to provide an adequate food output, which is not always increased output, while meeting societal objectives like environmental quality, viable rural communities, and enhanced farm family lifestyles. This new style of agricultural development involves many new perspectives in the
area of public policy. The need for sustainable agriculture began with the increased use of non-renewable resources by the agricultural industry and increased concern of petroleum shortages in the 1970s. Around this time there was also increased evidence of pollution in surface and groundwater caused by toxic chemicals that were applied to fields. Pesticide residues began appearing on farm workers, food, and non-target fields. There were also concerns of decreased plant and animal diversity and the overall costs of these harmful practices for future generations. Through public policy, new, less degrading methods of agriculture arose.

3.1. Technology

Technology is one of the main contributors to the negative impacts of current agricultural practices. There are two main forces that drive the use of new technology in the agriculture industry, one being the availability and low price of technologies and the other being incentives to adopt new technologies. The availability of technology depends on the means of research available. Research stems mainly from the private sector with nonfarm agricultural firms and the public sector at land grant universities. Public research has become a changing field in recent years because of the influence of private funding. Many universities are receiving decreasing amounts of funding from federal and state governments that has caused an increase in soft monies from the private sector. This new participation of the private industry in land grant universities has led to the privatization of products and processes through patents. The emerging field of biotechnology has also led to the engineering of materials that are protected as private property. These changing dynamics of agricultural technologies have changed the availability of technology and created an opportunity for new public policy.
Farmers adopt technologies for a number of different reasons including public policies like input subsidies, tax policy, technical and financial assistance, and commodity programs. Input subsidies encourage farmers to use purchased inputs like assistance from nonfarm firms in developing and testing inputs. Tax policies encourage farmers to increase their operations with incentives while technical assistance provides farmers with more information on the use of their purchased inputs rather than using their own resources. Lastly, commodity programs reduce price risks. Each of these factors is causing an increase in farmers outsourcing their work to nonfarm firms because of the public policy enacted by federal and state programs.

4. Cultural Dynamics

4.1. Sustainable Agriculture

While sustainable agriculture is necessary for environmental safety, it is also essential for the future wellbeing of humans as our population continues to grow, especially in developing countries. One major flaw in industrial agriculture as it is today is the overuse of freshwater. Less than 1% of all water on Earth is freshwater that both plants and animals need to survive and 70% of that water is used in agriculture. Because aquaponics recirculates water throughout the system, its freshwater use is about 10% of that used by conventional agriculture techniques. This impact on water consumption from the use of aquaponics makes aquaponics highly favorable in developing nations where water is a very precious commodity. An important benefit of sustainable local agriculture is closing the economic loop. When a consumer buys locally, their money stays in the community, while importing food products causes money to leave the local
community. Particularly in developing countries where the importation of certain food items may be prohibitively expensive due to energy costs, the ability to produce food locally is incredibly beneficial for the local economy, and reduces energy and resource consumption.

Amsha Africa Foundation is working in rural Kenya with local grassroots movements to implement effective sustainable aquaponics systems so that local communities can produce food with adequate nutrition on their own. The benefit of aquaponics as a closed system allows rural Kenyans to produce protein from fish and other nutrients from vegetables, while using minimal water and without the need for fertilizers. By helping local communities to produce their own food, the Amsha Africa Foundation is empowering rural Kenyans by giving them the benefits of food security and economic security, while also reducing their water usage and energy consumption.

The switch to sustainable agriculture from industrial agriculture, and particularly the use of aquaponics systems, is crucial in the attempt to save our world’s resources and improve the wellbeing of local communities. The benefits of sustainable agriculture on communities is most apparent in rural regions of developing countries. From an economic perspective, aquaponics is very beneficial as it costs less in the long run because there is no cost for fertilizers and water consumption is significantly reduced, and every penny spent on food is recirculated locally as opposed to entering the global market.

4.2. Agriculture in Costa Rica

As the negative impacts of unsustainable industrial farming have become more apparent to many, there has begun a new paradigm shift towards more sustainable
agricultural practices worldwide. The most effective way to sustainably farm is to reduce the size of the farming operation to lessen the environmental impact, and to distribute and consume the food product in the local community to reduce energy costs from transportation and packaging. Keeping food local is also a great economic benefit for local communities because it closes the economic loop, meaning that the money spent on food stays in the community instead of entering the global market. This economic benefit is also increased in cases where the importation of food costs more than growing it locally because of transportation and energy costs. This economic benefit of local sustainable agriculture is also especially impactful in rural regions and in developing countries where local communities are smaller and further apart.

While Costa Rica is considered a world leader in sustainable tourism and sustainable energy consumption, the tropical country lost a significant amount of its forests in the 20th century due to large scale industrial agriculture for exportation. In Costa Rica, advocates of sustainable agriculture are slowly influencing farmers and policy makers to realize that the current agricultural system is threatening the future availability of natural resources that farmers depend on. Slowly but surely, there is a growing interest in sustainable and organic farming among Costa Rican farmers. A primary influence for the increasing number of small farms embracing organic and sustainable agriculture in Costa Rica is the personal satisfaction that farmers get from producing healthy and nutritional food that is also not harmful to the Earth. Farmers take pride in this, and they also find empowerment in being able to eat and live sustainably and having control over the impact they have on their environment.
5. Aquaculture

5.1. Aquaponics Basics

Aquaculture, or the intentional rearing of aquatic animals and plants for food, is becoming an increasingly popular method of food production. An aquaponics system uses the symbiotic combination of an aquaculture (used for farming aquatic organisms such as fish) and a hydroponics system (a soilless method for growing plants). The water in the system flows from the fish tank into the media bed through a piping system. Once the nutrient rich water reaches the media bed, the needed nutrients are absorbed by the plants to be used as a natural source of nutrients. The water is then recirculated back to the aquaculture to begin the cycle again. Aquaponics systems aim to mimic cycles that occur in natural ecosystems and this limits the amount of labor and physical inputs into the system. Throughout history, the components of an aquaponics system have varied greatly, but the defining features that make this sustainable agricultural system an aquaponics system is the symbiotic waste-recycling relationship between aquatic animals and plant life.

5.2. Origins of Aquaponics

The first known occurrence of aquaponics technology was around 1,500 years ago in China.\textsuperscript{14} This early aquaponics system consisted of ducks, finfish, and catfish that were all fed separately. Aquaponics technology was used to avoid feeding the ducks, finfish, and catfish separately. The ancient Chinese farmers figured out a way to feed all of the animals in the system and fertilize the rice paddies, by only feeding the ducks. The ducks in this system were placed in cages above the finfish so that the ducks’ wastes, as well as any uneaten food, became food for the finfish. This removed the need to feed the finfish
with separate resources. The catfish were placed downstream from the finfish and ducks, so that the waste of both species flowed downstream and became the food for the catfish. The water that the catfish lived in was then channeled out to the rice paddies. This allowed for the rice paddies to be fertilized with the remaining wastes that the catfish did not consume from the system. By strategically organizing the animals in this system, the farmers were able to remove the added inputs of feed for ducks and finfish and fertilize for the rice paddies, reducing the overall system inputs.

The use of aquaponics technology was also independently discovered by the native Aztecs of Mesoamerica. Starting around 1000 AD, the Aztecs utilized a system they called “chinampas” for agricultural use. The chinampas were platforms elevated above freshwater lakes. Chinampas were built with layers of dirt, mud, and selected plants. The plants in these systems absorbed the nutrients provided by the natural decomposition of animal wastes in the lakes. The development of the chinampas removed the labor intensive step of water irrigation from terrestrial farming systems. This system showed early steps towards water conservation and management through aquaponics systems.

5.3. Modern Developments in Aquaponics

Modern day aquaponics systems are modeled after a system developed by the New Alchemy Institute. The New Alchemy Institute was founded in 1969 by John Todd, Nancy Todd, and William McLarney. The New Alchemy Institute aimed to create self-sustained agricultural ecosystems, without the use of fossil fuels. They created several “bioshelter ark” systems, which consisted of greenhouses that contained a system that sustainably produced fish and vegetables. The public dissemination of new agricultural
information made it possible for many other farmers who were interested in sustainable agriculture to reconstruct their aquaponics systems and develop the technology even further.¹⁶

In the 1980’s at North Carolina University, graduate student Mark McMurtry and professor Doug Sanders created the first closed loop aquaponics system. Water from the fish tank in their system trickled into their sand based media beds where it was then irrigated and used to fertilize tomatoes and cucumbers. The water was then drained back into the fish tank.¹⁷ The project noted many important breakthroughs in sustainable agriculture. They discovered that their integrated system of hydroponics and aquaculture required less than 1% of the water consumption that was needed for a pond culture producing similar yields.¹⁷

The next major development in aquaponics systems was the system made by Tom and Paula Sperano. This system was a modification of the North Carolina University system that utilized gravel media beds instead of sand media bed. The system was also modified to use an ebb and flow method instead of a continuous flow method.¹⁷ This aquaponics system was considered productive and practical. The creators of this aquaponics system also created a “how-to” manual with detailed instructions that allowed for their system to be highly duplicated by many farmers.¹⁷

In 1997, Nelson and Pade, Inc. followed the new, emerging trend of aquaculture and began to publish their informative journal, Aquaponics Journal.¹⁸ The journal was very popular among those interested in sustainable agriculture. It highlighted research developments, new technology and design decisions, and the current state of the
aquaponics industry. Between 1997 and 2013 they released 62 issues informing the public about aquaculture and aiding in the spread of aquaculture knowledge.¹⁸
Materials and Methods

1. Project Planning

The planning for this project started at the end of the Fall 2016 semester. The project planning and design was completed at the end of the Spring 2017 semester in early May. While in Costa Rica in August 2017, modifications were made to the original plans and design on an as needed basis. The final design is shown from several different views and layouts in Figure 1 below.
2. Materials

The materials used for each aspect of the project are broken into tables 1-4 below. Each table includes the materials used in the process and the quantity of each that was used for the project. The tables are broken down into applicable categories. Additional materials such as tools, screws, and other items are listed in a miscellaneous section in Table 1.

**Table 1.** The miscellaneous items used for the construction and implementation of the aquaponics system at the Punta Leona Resort and Hotel and Club.

<table>
<thead>
<tr>
<th>Tools/Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saws</strong></td>
</tr>
<tr>
<td><strong>Automatic screwdrivers</strong></td>
</tr>
<tr>
<td><strong>Assortment of screws</strong></td>
</tr>
<tr>
<td><strong>Cement</strong></td>
</tr>
<tr>
<td><strong>Paint brushes</strong></td>
</tr>
</tbody>
</table>
**Table 2.** The living aspects of the project: materials used for both the plant and fish needs.

<table>
<thead>
<tr>
<th>Plants and Fish Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Arugala</td>
</tr>
<tr>
<td>Cilantro</td>
</tr>
<tr>
<td>Romaine</td>
</tr>
<tr>
<td>American Lettuce</td>
</tr>
<tr>
<td>Fingerling Tilapia</td>
</tr>
<tr>
<td>Fish Feed</td>
</tr>
</tbody>
</table>

**Table 3.** The materials used and needed for both the tank, nutrient film technique (NFT), and media bed.

<table>
<thead>
<tr>
<th>Structural Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Liner</td>
</tr>
<tr>
<td>2600 L Fiberglass Tank</td>
</tr>
<tr>
<td>1600 L Fiberglass Tank</td>
</tr>
<tr>
<td>Air Pump</td>
</tr>
<tr>
<td>Airstone Tubing</td>
</tr>
<tr>
<td>Airstone</td>
</tr>
<tr>
<td>Plywood (2m by 4m)</td>
</tr>
<tr>
<td>5 cm by 10 cm planks (2m)</td>
</tr>
<tr>
<td>25 cm wide boards (2m)</td>
</tr>
<tr>
<td>25 cm wide boards (4m)</td>
</tr>
<tr>
<td>40 cm wide boards (2m)</td>
</tr>
<tr>
<td>40 cm wide boards (4m)</td>
</tr>
<tr>
<td>Deck Sealer (5 L)</td>
</tr>
</tbody>
</table>
Table 4. The materials requested and ordered by the Punta Leona staff that were used in the construction of the plumbing system for both aquaponics systems.

<table>
<thead>
<tr>
<th>Plumbing</th>
<th>Item</th>
<th>Quantity</th>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pondmaster 950 GPH Magnetic Drive Pump (SKU: 02720)</td>
<td>1 4 in. Poly Bulkhead Fitting (TF400)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pondmaster 2400 GPH Magnetic Drive Pump (SKU: 02750)</td>
<td>1 3 in. Poly Bulkhead Fitting (TF300)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. x 3/4 in. Sch 40 PVC Reducer (T.T.) Bushing MiPt x Fipt 439-210</td>
<td>1 92015-SS PVC black SLP x SLP 1-1/2 in. Bulkhead Fitting</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. x 1 in. Sch 40 PVC Reducer (T.T.) Bushing - MiPt x Fipt 439-211</td>
<td>1 4 in. PVC Termination Vent Screen (TV54)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. Schedule 40 PVC Female Adapter - Socket x FiPt (435-015)</td>
<td>2 Milwaukee 49-56-0249 Hole Dozer Bi-Metal Hole Saw S-3/4 in.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 in. Schedule 40 PVC Male Adapter - MiPt x Socket (436-040)</td>
<td>4 Milwaukee 49-56-0233 Hole Dozer Bi-Metal Hole Saw 4-1/2 in.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 in. Schedule 40 PVC Male Adapter - MiPt x Socket (436-030)</td>
<td>4 PVC Primer, Purple, 16 oz., for PVC (Gatey)</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1/2 in. Socket White Hayward® QCV Series Compact PVC Ball Valve</td>
<td>2 PVC Cement, Blue, 32 oz., for PVC (Gatey)</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>406-015-L 90° 1.5 in. elbow, COO: CHINA</td>
<td>14 1/2 in. x 260 in. PTFE Tape</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>409-015 1.5 in. street 90</td>
<td>4 Charlotte Pipe 1-1/2-in x 10-ft 330-PSI Sch 40 PVC DWV Pipe</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>401-015-L 1.5 in. Tee Sch 40, COO: China</td>
<td>8 Charlotte Pipe 1-1/2-in x 5-ft 330 Schedule 40 PVC Pipe</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>406-030S 90° 3 in. elbow COO: USA</td>
<td>2 Charlotte Pipe 4-in x 5-ft 220-PSI Schedule 40 PVC Pipe</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charlotte Pipe 3-in x 5-ft 260-PSI Schedule 40 PVC Pipe</td>
<td>3 417-040 45° 4 in. elbow</td>
<td>2</td>
<td></td>
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</tbody>
</table>

3. Media Bed

3.1. Bed Construction

The construction of the media bed required liner, wood, cement, waterproofing stain, paint brushes, supporting metal rods, hole saw drill bit, shank, and cinder blocks. The construction also required tools to physically construct the bed including screws, an automatic screwdriver, saws, a level, and a tape measure. Two media beds were constructed for this project, one that is 2 m by 4 m by 20 cm and one that is 2 m by 4 m by 35 cm. Figure 2 shows the facility where the media bed wood was purchased.
Figure 2. The wood yard where all of the wood was acquired for both the NFT (nutrient film technique) system and both media beds.

Before construction began, the hoop house ground was leveled and the dirt was compacted. The construction of each bed started by making a frame with either two 20 cm wide boards that were 4 m long and two 20 cm wide boards that were 2 m long, or two 35 cm wide boards that were 4 m long and two 35 cm wide boards that were 2 m long that accounted for the different depths of the media beds. Then, in each frame 5 cm by 10 cm planks that were 2 m long were spaced ⅓ of a meter apart inside the frame so that they were parallel to the 2 m long sides of each frame. This required eleven 2 m long planks per frame that lined up with the edge of the frame so that they took up the least amount of depth from each media bed. Once these planks are placed, they were secured with 2 screws per side of the plank to the frame. Once the planks were secured, a 2 m by
4 m pressure treated sheet of plywood was placed inside each frame. The sheets of plywood rested against the eleven planks and were pressed firmly against them so that the maximum depth of the bed was achieved again. The construction was completed with help of the maintenance staff of Punta Leona Resort. Figure 3 shows the constructed media beds.
Figure 3. Images of the completed beds before the wood was treated with waterproofing stain.
The wood used in the process was treated with deck sealer once the beds were constructed according to package instructions as seen in *Figure 4*. The sealer was used to coat the entire bed three times, with at least 24 hours of drying time left between each coat. Due the humidity and weather conditions in Costa Rica the sealer was allowed to dry for more than 24 hours in the cases of very wet days. The liner was then measured and cut for each bed to ensure it fit inside the constructed frames. A PVC piping frame was constructed and put inside the media bed on top of the liner to ensure that the liner was fit tightly into the media bed. The liner was folded over the edges and frame of the media bed and secured with thin pieces of wood and screws to keep the liner tight and properly installed. The process was repeated for the second media bed. See *Figure 5*. Once each bed was lined, the supporting legs of the media bed were constructed and added to the lined frames.

*Figure 4. The first coat of water resistant stain on the two constructed media beds.*
The media beds were placed approximately 1 meter off of the ground and were supported with cinder block legs to hold the weight of the large media beds. To raise the media beds 1 meter off of the ground, 3 cinder blocks were used per supporting leg. Eight supporting legs were used per media bed and placed in an equal grid to evenly support the bed, see Figure 6. Each media bed leg was placed on a cemented area that was set and hardened prior to the construction of the supporting legs. When the cement bases were set, two metal rods were put in place as well as the first cinder block to create a sturdy structure as the cement dried. The remaining cinder blocks were then placed through
these rods and stacked on the first cinder block with cement in between each block. Cement was also applied to all sides of the cinder blocks to fully seal the cracks between each cinder block. Once the blocks were cemented together, cement was put inside the holes in the cinder blocks to secure the blocks to the metal rods and therefore the cemented base. Once the legs were dried and completed, the frames were set onto the supporting legs as seen in Figure 6.
Figure 6. Images of the process of constructing the media bed legs and adding the constructed bed to the legs.
3.2 Grow Media

Medium sized red lava rock was used in the aquaponics system, seen in Figure 7. A total of 3600 L of red lava rock was divided between the two media beds after it was washed. The rocks were covered in a red dust that was rinsed off after multiple washes of the rock. The group spent 3-4 workdays washing the lava rock with a combination of buckets with holes drilled in the sides, screens, 2 hoses with running water, and shovels. The lava rock was washed twice outside of the media beds and then rinsed thoroughly in the media beds as well before the media bed was connected to the fish tank with the piping system. The methods of washing the rock outside of the media beds varied as the group worked to find the most productive and efficient way to wash the rock. There did not seem to be a particular method that was much more efficient than the other methods. Biochar is used to encourage the growth of bacteria and aerate the grow medium. The material will be evenly mixed in the grow medium in both the large and small media beds with 100 L and 50 L of biochar respectively. Biochar was not added to the system while the group was in Costa Rica, but it is suggested that the Resort purchase and use biochar.
Figure 7. The lava rock used in the media beds.
3.3 Plant Selection For Media Beds

The plant selection was dependent on the climate in Costa Rica and the depth of the media beds. The use of two varying depth media beds allowed one system to grow deeply rooted vegetation and the other system to grow more shallowly rooted vegetation. Plants that could be grown in the media bed with a depth of 0.15 m include: basil, mint, cilantro, oregano, parsley, rosemary, arugula, lettuce, kales, collards, and cabbage. Plants that could be grown in the media bed with a depth of .3 m include: tomatoes, squash, zucchini, broccoli, peppers, and cucumbers. The selection of plants varied by consumer demands and the preferences of the hotel authorities. The plants were acquired three weeks prior to planting and can be seen in Figure 8.
3.4 Media Bed Planting

After the completion of the plant bed, the plants needed to be planted in the media beds. The grow grips were used to maintain the health and structure of the young plants. Figure 9 shows an example image of the grow grips used in the system. The grow grips were placed between the roots and the stem to ensure proper plant support. Then, holes were dug in the grow media at a depth that allowed the roots of each plant to reach the water level of the media bed. Once the each plant was placed in the respective hole, it was covered back up with the lava rock, so that the grow grips were fully covered. Each plant was spaced according to the specific plant type. The larger bed had six rows of plants and with three to four plants per row. The smaller plant bed had approximately
twelve rows of plants and each row contained eight to ten plants per row. Each media bed was filled with the appropriate amount and type of plants.

Figure 9. The process of placing the grow grips onto a lettuce plant to be transplanted into the media beds.19

4. Fish Tank

4.1. Tank Construction

Two separate fiberglass tanks were ordered by the staff at Punta Leona according to the specifications given to the staff by the group prior to arriving in Costa Rica. Once the group arrived, two holes were dug. One of the holes measured 2 m long by .6 m wide by 1 m deep for the smaller fish tank. The hole for the tank that corresponds with the larger media bed was dug to be 2 m long by 1.2 m wide and 1 m deep as seen in Figure 10. One tank measured
.6 m by 2 m by 1 m and the other tank measured 1.2 m by 2 m by 1 m. Approximately .25 m of the tank will not be directly under the media bed, for pipetting purposes for each tank and media bed system. The holes were dug a little larger than the actual tank size and filled with roughly ¼ of a meter of gravel in each hole to keep the tanks level. The tanks were then each placed inside their respective holes and the excess hole space was filled with dirt gradually to insure that the dirt settled properly. A level was used to make sure that the tanks were level. The tanks were filled up with water and drained twice before the tanks were finally filled up with water to wait for the fish arrival a few days later.
Figure 10. The first image shows the hole dug for the smaller system’s tank and the second image shows the hole for the larger tank with gravel added.

4.2 Water Quality Monitoring

Water quality in the fish tank was monitored using basic test strips every day for the first 5 days to ensure stability in the system. Once the system had stabilized, water quality was checked every 2-4 weeks to ensure proper fish and plant health. Total nitrogen must be monitored and can be monitored using test strips. The test strips should be quickly dipped into the water and then removed. The test strip instructions should be followed so that the appropriate amount of time has passed before the color of the test strip is compared to the provided guide for nitrogen levels. Nitrogen levels should be as follows: ammonia should stay below 1.0 mg/L, Nitrite levels should stay below .25 mg/L, and Nitrate levels should
stay below 150 mg/L. The same procedure for the test strips should be followed to test the pH and water hardness. pH levels should stay between 6-7.5 for ideal plant and fish health. Water hardness should fall in the range of 60-140 mg/L. The temperature should be tested with a thermometer and should stay in the range of 27-30 degrees Celsius.

Before the fish arrived, air stones were installed into the fish tank. The larger tank has two air stones and two air pumps. Each air pump has two air outflows. Each air pump will have one air stone that will set approximately .75 m into the tank off centered on opposite sides of the tank, shown in Figure 11. The other outlet for each air pump will reach the bottom of the tank with about .75 m of length of tubing, then the tubing is split using a piece that splits the air flow into two flows. Each of these two flows will lay parallel about 30-40 cm apart on one side of the ground of the tank. The other two flows coming from the other air pump will lay on the other side on the tank. These four lines are two meters long with holes poked (with a nail) approximately every 15-30 cm apart. See Figure 11 below for a depiction of the set up. The air stone lines also have holes poked in them to maximize oxygenation of the tank.
Figure 11. The air stone set up in the larger of the two fish tanks, with two air pumps and two air stones.

The small tank has a similar set up. The smaller tank has one air stone and one air pump. The line to the air stone (placed in the center of the tank) is about .75 m long and will be placed .5 meters into the tank, as close to center as possible. The line has holes poked with a nail about 15-30 cm apart. The other outlet of the air pump has about .75 m of tubing running from the air outflow to the bottom of the tank, shown in Figure 12. Then, a splitter was placed and two 2 m lines are attached. These lines have holes poked in them every 15-20 cm and run across the bottom of the tank on opposite sides of the air stone. The air stone and the two lines should be placed at even spacing from one another. See Figure 12 for a schematic of the air stone tubing in the smaller tank.

Figure 12. The layout of the air stone and air pump in the smaller of the two tanks.
5 Plumbing

5.2 Main Media Bed Piping Layout

The pipes used for the inflow of water to the media beds for both aquaponics systems were 1-½” Schedule 40 PVC pipes. Because the fish tanks were placed along the long edge of the media beds, the piping system enters the media bed at approximately the midpoint of the long edge on both beds. *Figure 13* and *Figure 14* provide a visual overview of the piping layout.

*Figure 13. Labeled image of piping layout, displaying Points A-F, J, and L. NFT not shown.*
5.2.1 Point A

Point A (shown in Figure 13) is the location of the pump. The pump draws water from the tank and propels it vertically towards the media bed in the direction of Point B (shown in Figure 13). The pump that was chosen for the smaller system was the Pondmaster 9.5 (shown in Figure 15), which has a nominal flow rate of 950 gallons per hour (GPH). The pump that was chosen for the larger system was the Pondmaster 24 (shown in Figure 16), which has a nominal flow rate of 2400 GPH. Both pumps came with a pre-filter that attaches to the inlet of the pump. The hole sizes on the pre-filters are larger than the smallest fish, so a finer metal mesh screen was rolled up and inserted into the filter (shown in Figure 17). The outlet of the Pondmaster 9.5 has a ¾” MIPT
connection, and the outlet of the Pondmaster 24 has a 1” MIPT connection. The recommended pipe diameter to use with these pumps is at least 1-½” \(^2\). A ¾” FIPT x 1-½” MIPT reducer was attached to the outlet of the Pondmaster 9.5 and a 1” FIPT x 1-½” MIPT reducer was attached to the outlet of the Pondmaster 24. A 1-½” FIPT x Socket adapter was then attached to the 1-½” MIPT end of the reducers that are attached to both pumps, so that non-threaded PVC could be attached (shown in Figure 18).

![Figure 15. Stock photo of the Pondmaster 9.5 pump, used in the smaller system.](image)
Figure 16. Stock photo of the Pondmaster 24 pump, used in the larger system.

Figure 17. The pre-filter on the pump inlet, with a finer metal screen rolled up and inserted inside.
5.2.2 Point B

At Point B, the flow of water can split and travel in the direction of Point C (shown in Figure 13) and/or Point D (shown in Figure 13) by means of a Tee joint. Located between Point B and Point C, and between Point B and Point D, are PVC ball valves that can fully regulate the flow of water. When the handle of the ball valve is parallel to the pipe it is in the open position. When the handle of the ball valve is perpendicular to the pipe it is in the closed position.
5.2.3 Point C

Point C is the exit point for the ball valve bypass. When the ball valve between Point B and Point C is opened, water is diverted back to the tank. This ball valve between Point B and Point C, and the ball valve between Point B and Point D, are used to control exactly how much water is directed to the bed, and is capable of cutting off the flow to the bed entirely if needed.

5.2.4 Point D

Point D is a Tee joint located at the upper edge of the media bed. The flow of water through Point D splits into two paths: horizontally toward the wall of the media bed, and vertically toward the NFT tubing (not shown).

Between Point D and Point E is the wall of the media bed. For piping to travel through a wall, a bulkhead fitting was needed. The bulkhead fitting shown is for 1-½” PVC pipes, and required a 2.5” hole be drilled through the wall of the bed. Both sides of the bulkhead fitting have FIPT connections, so a 1-½” MIPT x Socket PVC adapter was attached to both sides of the bulkhead fitting so that non-threaded PVC pipes could be attached.

5.2.5 Point E

The flow of water travelling from Point D to Point E (shown in Figure 13 and Figure 14, respectively) is split in half at Point E by a Tee joint and diverted to the left and to the right. Point E is located at approximately the midpoint of the long side of the bed. From Point E onward, the system is nearly symmetrical.

The center point along the long side of both beds is at a point where the plywood is conjoined and overlapping, increasing the width from 1.8 cm to 3.6
cm. The 1-½” bulkhead fitting cannot attach/screw together at that width, so it must be displaced to the side where the width of the wall is thin enough for attachment (1.8 cm).

On the smaller bed, the center mark is 3.7 cm away from the plywood overlap, on the side of the overlap. The 1-½” bulkhead is a maximum 10.0 cm across, so the minimum distance that the hole should be marked is 5 cm away from the overlap. The hole was marked 5.6 cm away from the plywood overlap in case of drilling error. The total horizontal displacement of the inflow hole on the smaller bed is 9.3 cm.

On the larger bed, the center mark is about 0.3 cm away from the plywood overlap, on the single-plywood side. The new hole was also marked 5.6 cm away from the plywood overlap in case of drilling error. The total horizontal displacement of the inflow hole on the larger bed is about 5.3 cm.

5.2.6 Point F

The flow that is split to the left and to the right at Point E then travels along the long side of the bed to the first two corners of the bed, labeled Point F (shown in Figure 13 and Figure 14). Measurements of the lengths of PVC that were cut to be used from Point E to Point F are shown in Table 5. At Point F, the flow of water is redirected by a 90-degree elbow to travel along the short sides of the bed. Located between Point F and Point G (shown in Figure 14) is a ball valve. Prior to the installation of the ball valve, the flow rate to the NFT system was insufficient. Therefore, the ball valve was installed to throttle flow to the main piping system, resulting in increased flow to the NFT system.
Table 5. Measurements of PVC that was cut for Point E to F in both systems.

<table>
<thead>
<tr>
<th></th>
<th>Left Side</th>
<th>Right Side</th>
<th>Offset of Point F from Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger System</td>
<td>195 cm</td>
<td>184 cm</td>
<td>5.3 cm to the right</td>
</tr>
<tr>
<td>Smaller System</td>
<td>199 cm</td>
<td>181 cm</td>
<td>9.3 cm to the right</td>
</tr>
</tbody>
</table>

5.2.7 Point G

Point G is located at approximately the midpoint of the short side of each bed. At Point G, the flow travelling parallel to the short side of the bed is redirected by a 90-degree elbow so that the flow is pointed in the direction of the center of the bed. Immediately after passing through the 90-degree elbow, the flow is met by a Tee joint which diverts the flow to the left and to the right in a symmetrical manner (shown in Figure 19).
5.2.8  Point H

Point G directs the flow of water to Point H (shown in Figure 14), which is located at each corner of the bed. The length of PVC that was cut to join Point G and Point H was 82 cm. Point H is equipped with a 90-degree elbow that directs the flow downward directly into the bed (shown in Figure 20). Because the flow of water is split nearly symmetrically into two equal flows at Point E, and again at Point G, the flow rate out of Point H is the same for all four corners of the bed.

Figure 19. A close-up view of Point G.
Figure 20. A close-up view of Point H, the outlet point of water into the bed.

5.2.9 Point I

Point I (shown in Figure 14) is the location for the outflow of water from the bed, located near the center of the bed. The outflow piping is 4” PVC, and required a 4” bulkhead fitting to pass through the base of the bed. The bulkhead fitting that was used required a 5.75” hole be drilled. Both sides of the bulkhead fitting have FIPT connections, so a 4” MIPT x Socket adapter was attached to both sides of the bulkhead fitting so that non-threaded PVC pipes could be attached (shown in Figure 21).

The outflow piping inside the bed is vertically oriented, and is hidden beneath the grow media. This is because the bed is split into wet and dry zones, with the top of the wet zone being the top of the outflow.
The wet zone of the large bed was decided to be approximately 19-20 cm, so that became the desired height of the outflow. The outflow bulkhead protrudes into the bed 3.5 cm. The 4” MIPT x Socket adapter that was placed on top adds another 6 cm. The termination screen, which fits over 4” PVC, is about 9.5 cm long. The combined height of these pieces was about 19 cm. The length of PVC that could fit into the termination screen was about 9.4 cm, and the length of PVC that could fit into the 4” adapter was 5.3 cm. The required length of 4” PVC pipe to connect the components was therefore 9.4 cm + 5.3 cm = 17.7 cm. The 4” adapter was then equipped with four evenly placed ½” holes. This was done to prevent water from stagnating at the base of the outflow, as well as allowing the bed to drain significantly when the pump is shut off. Wedged in place between the termination screen and the pipe that is inserted into it is a finer mesh screen to prevent rocks from entering.

The wet zone for the small bed was decided to be about 9.5 cm in depth. The combined height of the bulkhead fitting, thread adapter, and termination screen was 19 cm. The termination screen was shortened from 9.5 cm to 3 cm, and the thread adapter was shortened on the socket side by 3 cm. The inner length of this new termination screen is about 2.4 cm. The inner length of the 4” adapter, once cut, became 2.3 cm, so the length of PVC that was cut to connect the termination screen to the adapter was 4.7 cm. The 4” adapter was then equipped with eight evenly placed ¼” holes to prevent water stagnation.

Wedged in place between the termination screen and the pipe that is inserted into it is a finer mesh screen to prevent rocks from entering. The outflow
assemblies on the inside of the bed for both beds were not cemented in place. This was done so that it could more easily be disassembled if maintenance is necessary.

![Image](image_url)

*Figure 21. 4” bulkhead fitting and 4” PVC MIPT x Socket adapter for outflow on the left (Point I), and 3” bulkhead fitting and 3” PVC MIPT x Socket adapter for overflow on the right (Point K).*

5.2.10 Point J

Point J (shown in *Figure 13*), is the point at which water is returned to the tank after passing through the outflow assembly. The water flowing through the outflow assembly, from Point I to Point J, drops vertically down to the height of the fish tank, where it then meets a 90-degree elbow that angles the flow in the direction of the fish tank. When the outflow pipe meets the edge of the fish tank, a 45-degree elbow directs the flow downward.
In the larger system, the vertical distance between the 4” MIPT x Socket adapter attached to the bulkhead fitting at the bottom of the bed and the lip of the tank is about 31 cm. The length of the 4” 90-degree elbow is about 16.3 cm, and the inner length that PVC can fit into it is about 4.2 cm. The inside length of the 4” MIPT x Socket adapter is 5.3 cm. Therefore, the length of PVC that extends vertically downward should have been about 24.2 cm. The length of PVC that was cut was instead 23.5 cm to ensure that it would fit properly. In the smaller system, the vertical distance between the adapter and the lip of the tank is about 27 cm, so the calculated length of PVC that extends vertically downward would be about 20.2 cm. This was also undercut to be 19 cm to ensure proper fitting.

While the PVC for the vertical descent in the outflow assembly was undercut to ensure that it would fit, the horizontal length of PVC directed towards the tank was overcut to ensure that it would fully reach. In the larger system, the horizontal distance between the 4” 90-degree elbow and the lip of the tank is about 41 cm, so the length that was cut was 43.5 cm. In the smaller system, the horizontal distance between the 4” 90-degree elbow and the lip of the tank is about 75 cm or greater, so the length cut was 83 cm.

5.2.11 Point K

Point K (shown in Figure 14) is the location of the overflow, located near the center of the bed. The overflow piping is 3” PVC, and required a 3” bulkhead fitting to pass through the base of the bed. The bulkhead fitting that was used required a 4.5” hole be drilled. Both sides of the bulkhead fitting have FIPT connections, so a 3” MIPT x Socket adapter was attached to both sides of the
bulkhead fitting so that non-threaded PVC pipes could be attached (shown in Figure 21).

The overflow piping inside the bed is vertically oriented, and rises above the grow media. The height of the overflow is intentionally above the rock level, and is only in place as a cautionary measure to prevent the tank from overflowing in case of a blockage in the outflow. The height of the overflow in the large bed was decided to be about 30 cm. The height of the overflow in the small bed was decided to be about 17 cm. The combined height of the 3” bulkhead and the 3” MIPT x Socket adapter is 9 cm. That means that the large bed overflow needs to be 21 cm taller and the small bed overflow needs to be 8 cm taller. The inner length of the 3” adapter is 5 cm, so the PVC that needs to be cut for the overflow should be 5 cm longer than the height left: 26 cm for the large bed and 13 cm for the small bed. The same finer mesh screen that was used for the outflows was placed inside of the 3” adapters before the PVC was inserted, securing the screen in place.

5.2.12 Point L

Point L (shown in Figure 13), is the point at which water is returned to the tank, in the off chance that the outflow piping is blocked and the overflow assembly becomes utilized. The water flowing through the overflow assembly, from Point K to Point L, is designed in the same way as the outflow assembly, but with 3” PVC instead of 4” PVC. The flow drops vertically down to the height of the fish tank, where it then meets a 90-degree elbow that angles the flow in the
direction of the fish tank. When the overflow pipe meets the edge of the fish tank, a 45-degree elbow directs the flow downward.

In the larger system, the vertical distance between the 3” MIPT x Socket adapter that is attached to the bulkhead fitting at the bottom of the bed and the lip of the tank is about 32 cm. The length of the 3” 90-degree elbow is about 15.5 cm, and the inner length that PVC can fit into it is about 5 cm. The inside length of the 3” MIPT x Socket adapter is about 5 cm. Therefore, the length of PVC that extends vertically downward was calculated to be 26.5 cm. The length of PVC that was cut was instead 25.5 cm to ensure that it would fit properly. In the smaller system, the vertical distance between the adapter and the lip of the tank is about 26 cm, so the calculated length of PVC that extends vertically downward would be about 20.5 cm. This was also undercut to be 19 cm to ensure proper fitting.

While the PVC for the vertical descent in the overflow assembly was undercut to ensure that it would fit, the horizontal length of PVC directed towards the tank was overcut to ensure that it would fully reach. In the larger system, the horizontal distance between the 3” 90-degree elbow and the lip of the tank is about 42 cm, so the length that was cut was 43 cm. In the smaller system, the horizontal distance between the 4” 90-degree elbow and the lip of the tank is about 75 cm or greater, so the length that was cut was 81 cm.

5.2.13 PVC Construction

PVC pipes that were used were measured using a measuring tape, and marked around the circumference of the pipe for each pipe. The PVC pipes to be
cut were propped up on a cinder block, and then rotated and sawn from all sides to ensure a flat and even cut. After being cut, the end of the PVC pipes were sanded down until they were smooth. To connect a PVC pipe into a PVC joint or adapter, PVC glue was required. PVC glue was applied conservatively to the inside of the joint/adapter and then applied to the outside of the pipe to be connected. After waiting a few seconds, the pieces were connected and set aside to dry and seal, which happened very quickly.

5.3 Nutrient Film Technique

A second type of grow media, aside from the media bed was used. This method is called nutrient film technique which consists of a shallow stream of water passing through the bare roots of the plants in a water channel. This system was constructed on top of both media beds using four 10 ft PVC pipes with a diameter of 4 inches, for each respective bed. A three triangular wooden structures were constructed with a height of 1 meter and a base of 2 meters using 2 inch x 4 inch blanks for each bed. These triangular wooden structures rested on top of the media beds and were spaced one meter apart along the PVC pipes. There were two pipes at the top of the triangular structures and two halfway down the side of the triangular structures on each bed. Using a hole saw drill bit and shank, 3 inch holes were drilled in each of the PVC pipes, equally spaced with 11 holes per pipes. Each pipe was capped on one end using PVC cement. On the other end, a partial cap with 1 inch cut off the top of the cap was cemented to the PVC pipe to slow the flow of water. At the site of the water outflow by the pump, a valve was attached where a polyethylene pipe carries the water to top of the first wooden triangle site. This tubing flows into a 4-port full flow manifold. Each valve was then be fitted with 0.5 inch
polyethylene tubing. Each of the smaller tubes fit into one of the four capped ends of the PVC piping. Each of the 3 inch holes in the PVC were fitted with 3 inch growing baskets. These baskets were filled with red lava rock as a growing media, where the greens were planted. The outflow of each of the PVC pipes has a small rain chain attached that guides the outflow water to the media bed with minimal splashing and plant disturbance. This construction and design was repeated identically above both media beds.
Figure 22. Images depicting different stages of the nutrient film technique construction.
Discussion

1. Food Production

Punta Leona Resort previously sourced its fish from fish farms throughout the country; all fish served in the restaurant were captive raised. The aquaponics system not only works to replace previously purchased fish, but also some meats that were featured in the hotel restaurants. Agribusinesses rely on fossil fuels to drive their waste intensive production systems to produce large quantities of goods that are packaged and shipped long distances before arriving at their final destination, increasing the embodied energy and externalized costs of the products. The use of local, sustainable aquaculture minimizes not only the physical distance that the food has to travel to the table, but also the overall cost-intensive energy put into the product. Fish food is a key input and can be managed to limit wastes associated with the system. In the localized aquaponics system, fossil fuels are used to produce the electricity that run the water pumps in the system, but the rest of the system relies on human-based power. The scale of the operation allows for workers to provide the power that fossil fuels provide for larger systems, decreasing the environmental costs associated with the localized aquaponics system and the waste associated with this method of production. The produce grown in the aquaculture system can include lettuce mixes, herbs, and vegetables, based on demand from the restaurants. This allows for an adjustment of production based on needs and product availability, limiting wasted resources. The ability to harvest fish from the system on an as-needed basis also limits the amount of food that must be stored at one time. Fish can be kept alive until they are needed, reducing the risk of spoilage and need for storage capacity. Aquaponics systems are known for their ability to recycle water, therefore reducing water
consumption for both the produce and fish grown in the system. Traditional agribusinesses, crop production, and fish farms are water intensive operations that often use ineffective methods of water management, magnifying water waste. Aquaponics systems recycle and efficiently use water and the nutrients naturally produced in the system so that no additional fertilizer inputs are required. This reduces the inputs necessary to produce the same products, with a lower use of environmental resources. Factory farmed meats may be subject to antibiotics and other injections as required by agribusinesses, creating additional inputs for these larger, mechanized systems. Cash crops such as tomatoes typically require harvesting equipment, fertilizers, pesticides, herbicides, water, land, and transportation. The system is water-intensive and relies heavily on manufactured chemical inputs. The use of natural ecological processes in aquaculture saves the producer both added inputs and environmental costs throughout the growing process of both the fish and the produce. The ability to adjust a localized system to the direct production needs creates a versatile system that can minimize wasted produce and increase availability of high demand products locally.

2. Ethics of Food Production

Factory farms are created to “grow” or raise livestock as quickly as possible in confined animal feeding operations, using the least amount of monetary resources and expenses leading to high environmental and social external costs. Confined animal feeding operations and feedlots are used to raise a large quantity of animals to slaughter size in limited space. The use of factory farms and feedlots creates millions of tons of waste per year; including 19 million tons of pig production waste a year in North Carolina alone. This waste is subject to improper disposal, leaks, and other methods of
contaminating the nearby environment, causing air, water, and land pollution that harms not only the natural environment but the lives of those who live near these operations. The odor and associated air pollutants from pig farms can burn the eyes and lungs of workers and local residents. This leads to health problems and a reduction in the quality of life for those affected. Local residents and workers have the right to live in an environment that does not cause excessive health problems from the external costs created by a business. Agribusinesses often do not pay fair wages and put workers in unsanitary and even dangerous work conditions. Factory farming has led to livestock with new illnesses called “production diseases” that result from injuries and infections caused by the living conditions and the diets fed to these animals that aim to maximize growth as opposed to maintain long-term health of the animals in these systems. Such illnesses raise the ethical issue of humane animal treatment. Another point of questionable animal treatment in factory farm arises from facts about animal living conditions. For example, the standard set for the “humane” living space for a chicken is a standard 9” by 11” piece of paper. The conditions in large fish farming operations are comparable to those of terrestrial animals in factory farming operations. Large scale fish farms create poor, dirty conditions that physically stress the fish in small, confined pools. The goal of the smaller scale, localized aquaponics system is to minimize these externalities by reducing environmental costs and maintaining proper conditions and wages for workers. The implemented aquaponics system is filtered by plant biomass that is appropriately scaled to keep the conditions inside the fish ponds ideal. The ponds are also monitored weekly by the staff to ensure ideal conditions for the fish to minimize stress inducing conditions that can harm the quality and health of the tilapia in the
system. Smaller, sustainable agricultural systems, like the aquaponics system, work to ethically and fairly balance social, environmental, and economic aspects, while creating healthier products for the consumer.

3. Municipal Solid Waste

One of the major concerns with food production and global resource depletion as a whole is the issue of municipal solid waste (MSW). MSW is defined by the United Nations as “waste originating from households, commerce and trade, small businesses, office buildings, and institutions.” This “includes bulky waste (e.g. white goods, old furniture, mattresses) and waste from selected municipal services, e.g. waste from park and garden maintenance, waste from street cleaning services, if managed as waste.”

Sarah Moore takes the concept of MSW further by emphasizing the most common form of MSW is packaging, specifically for food and beverage. While this waste can become a commodity, a political tool, and even part of a social structure through the global flows of garbage created by consumerism and entropy in the waste system, it is still fundamentally an environmental problem, as seen on a small-scale at Punta Leona. With the food systems existent before the aquaponics system, the menu relied heavily on shipments of food from within Costa Rica and internationally. Due to shipping and sanitation regulations, all of these shipments of food must be packaged in a variety of plastics, Styrofoam, and cardboard. By implementing a localized system on the property of the resort, packaging can be nearly eliminated. That is not to claim that the aquaponics system has no ecological costs; many of the materials needed to construct the aquaponics system were not available within the country and had to be shipped in packaging, and travel great distances, which increased the MSW added to global flows. Despite the
additional MSW needed to ship aquaponics materials internationally, having a localized food production system will minimize Punta Leona’s contribution to global flows of MSW due to reduced food packaging required from farm to table.

4. Food Miles

Food miles also play an important role in comparing the ecological value of the conventional food production at Punta Leona versus the food production after the installation of the aquaponics system. The definition of food miles has been variably used since its coining in the early 1990s by Tim Lang. The term is defined by Lang as the distance food travels, as well as its ecological impacts accumulated all along the food chain. In other words, a food miles analysis focuses on the embodied ecological footprint of any given food product. The restaurant at Punta Leona currently serves foods from vendors within 100 km radius, as well as places as far as China. Because the restaurant served almost all meat heavy dishes, their food had high embodied energy and food miles. With the introduction of the aquaponics system, the food miles are significantly reduced although there are still high levels of embodied energy in the materials sent great distances to construct the system. Although small parts in the system have high embodied energy, the plant seedlings, grow medium, and fish all came from within 100 km of the resort. These are the three products that need replacing frequently so over time the overall food miles of the food from the system will balance out. Each of these inputs still are managed with cradle to cradle practices as the unused fish and plants removed from the system are composted on site while the old grow medium is used in landscaping for the property. “The Food Miles Report” acknowledges that there are some trade-offs when it comes to energy consumed in agriculture production for transporting
products long distances. While it may seem energy intensive to transport food long distances, it may be even more energy intensive to create the proper conditions to grow locally depending on the climate. In the design of the aquaponics system, only plants that can grow efficiently in the local climate were selected to reduce the need for energy intensive agricultural systems. With this consideration it makes ecologically justifiable for Punta Leona staff to purchase some foods from greater distances due to the limited variance in seasonality locally. Overall, by producing commonly used vegetables like salad greens, cucumbers, and tomatoes, Punta Leona is decreasing the food miles of every meal served compared to their original imports through a reformist approach to sustainable agriculture.

5. Degradation and Marginalization through Tourism

Because Punta Leona Hotel caters mainly to international tourists, visiting consumers must be part of the political ecological analysis of the food production systems. Throughout the Pacific Coast between the cities of Jaco and Punta Leona, large resorts litter the coastline and offer lavish meals and living situations, while just outside the gates of these resorts lie small towns with contrasting living conditions. The degradation and marginalization thesis argues that otherwise environmentally innocuous production systems undergo transition to overexploitation of natural resources on which they depend as a response to state development intervention and/or increasing integration in regional and global markets. As a result, this leads to a cycle of increased poverty locally and even more overexploitation of resources. Because Punta Leona is connected to the global market of tourism, they are exploiting their local resources to benefit the temporary residents of the area and the costs of such are often borne by the lower class
permanent residents. The dangerous cycle of resource exploitation can be limited by scaling down resource-intensive systems like food production. By using small scale agricultural production systems like aquaponics systems, Punta Leona is exploiting fewer resources than they were with their initial food production practices, but may also be taking away work from the already marginalized populations in Costa Rica. The aquaponics system is by no means a complete technical solution. It has a small impact in the grand scheme of the overexploitation of resources caused by tourism in Costa Rica. Still, small efforts can lash up to form big impacts. The aquaponics system should be used as an educational tool for tourists to learn how to change their travel practices and behavior to reduce their environmental impact. Overall, the integration of the aquaponics system is just one small step in scaling down the natural resource usage at the resort and its connection to the global market.
Conclusion

An aquaponics system was integrated at Punta Leona Resort and Hotel in Costa Rica as a method to counter the overwhelmingly dominant method of mass food production used in so many areas around the world today. The system was created to help meet sustainability goals of the resort and reduce to persistent environmental problems associated with the rise of agribusinesses, fossil fuel use, factory farming, and degradation and marginalization of communities through tourism. Large scale production methods used by agribusinesses increase the use of fossil fuel driven machines that lead to many forms of environmental degradation, including land erosion, air and water pollution, excessive water exploitation, and large quantities of municipal solid waste. The implemented aquaponics system is only capable of producing a small amount of the food consumed at Punta Leona and so the system would need to be scaled up in order to provide a significant portion of the food consumed at the resort. The implemented aquaponics system uses natural ecological processes to recycle nutrients and water, minimizing overall system inputs and waste. Local systems reduce the embodied energy in the food products from cradle to table to grave by cutting out many of the additional processes required when mass producing food far from its final destination that must also adhere to specific food safety standards throughout all processes. The methods used to produce, transport, and store food products in agribusinesses are largely unethical using social and environmental standards. These businesses maximize their profits by minimizing product prices with resulting externalities that have environmental and human impacts. These externalities range from the health and treatment of workers, local peoples, and consumers to the health of the local environments and the animals in these systems. Through the implementation of their localized agricultural system, Punta Leona is not only able to produce its own local, sustainable fish and produce while limiting
externalities, they are also able to use their methods as a teaching tool to help pave the way for smaller scale sustainable agriculture systems to set hold in Costa Rica and other surroundings areas.


