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Research Article

Improvement of Aquaculture Profitability and Sustainability through Integration with Duckweed

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Abstract

Aquaculture is increasingly to grow fish for food, repopulation, and other necessities. Maintaining high-quality fish while saving on resources and expenses is key for both farmers and consumers. Our study, which used Red Belly Pacu fish, focused on the effectiveness of utilizing duckweed as part of the feed and as a reducer of pollutants in the tanks. This study's goal was to see if we can use this alternative to reduce the cost of fish feed without having detrimental effects on fish growth, as well as provide possible benefits in terms of tank cleanliness. The model comprises 4 tanks, each with varying amounts of duckweed (both for feeding and filtering purposes). Over 2 years, we measured fish weight, water temperature, and water quality parameters such as pH, nitrite levels, and ammonia levels. After analyzing the data with fixed effects and random effects models, we concluded that if up to 40% of the total fish feed is replaced with duckweed, fish growth will not be harmed. Although more studies must confirm lower pollutant levels in tanks due to duckweed, our study showed some indication that this was true. If our model of using up to 40% duckweed in tanks is followed, farmers can be expected to save about 15-20% in production costs while maintaining the same quality of fish.

Introduction

Optimized solutions in agriculture are critical for success in dramatically increasing food production. These solutions should aim to minimize the use of land, water, and energy while producing a needed resource. To this end, aquaculture is a rapidly emerging technology, and integrating recirculating aquaculture systems with the production of plants using hydroponics, namely, aquaponics [1], can potentially meet these aforementioned challenges. These technologies can, for example, fit into the urban agriculture paradigm (e.g., [2], among others) as a platform that is both cost-effective and eco-friendly, allowing consumers to become farmers and produce food to feed both themselves and the local communities. The aquaponics system can fit neatly into urban settings and intertwine crop and fish production ([3,4], among others). The basis of aquaponics is the circular economy system, which in contrast to a linear 'take-make-waste' system, reuses byproducts normally deemed waste to generate usable products [5]. Not only do the plants grown in the system benefit from the fish waste being used as a nutritional fertilizer of sorts, but the fish may benefit as well in terms of cleaner water. Also, some plants, such as the duckweed we used in this study and some species of algae, can act as a partial substitution of commercial fish feed.

While focusing on photosynthesis-based filtration systems [6], this paper shows that through assimilation of organic pollutants produced by the fish excretions into biomass, the cost of intensive fish farming through aquaculture declines by 15-22%. This is achieved by using small aquatic plants from the Lemnaceae family, i.e., duckweed [7]. These fast-growing perennial plants' ability to rapidly absorb nitrogen and phosphorous compounds from organics-rich water bodies [8] minimize the need for fertilizer while helping to reclaim freshwater for beneficial reuse purposes. In addition, the resultant protein-rich duckweed biomass [9-11] is an excellent source of feed for aquaculture. Such solutions assure access to affordable and nutritious protein-rich food on limited farmland while reducing water consumption.

To arrive at these conclusions, two experiments were managed and used to test the following two hypotheses. The first hypothesis was that the addition of duckweed into the aquaculture system would reduce the level of pollution and thus improve water quality. The second hypothesis was that duckweed's addition does not affect the growth of fish compared to a pure commercial feed diet. To test these hypotheses, primary data was collected and analyzed. Our analysis revealed evidence supporting the hypothesis that duckweed could reduce pollutants in the system, specifically on ammonia levels. We also found statistical evidence that supports the hypothesis for duckweed as a viable alternative to traditional commercial feeds.

Material and Methods

The data was collected over a period of 2 years. Tanks A (30 gallons) and B (20 gallons) were the initial aquariums that were set up in order to figure out the best way to run a controlled experiment (Figure 1). Tanks C1, C2, D1, D2 (55 gallons, each) came about a year later and is where most of the variables such as ammonia, nitrate, and nitrite levels were monitored (Figure 2). Both systems housed Red-belly Pacu fish.

The feed provided to the Red Belly Pacu was Tetra: TetraCichlid Flakes (for fish less than 10 grams) or Tetra: TetraCichlid Floating Cichlid Sticks (for fish greater than or equal to 10 grams), or a combination of commercial feed and duckweed from the Lemnaceae family. The fish were fed daily, and the feed was left in the tank for five minutes, after which the remaining feed was removed to prevent overfeeding. Removing the uneaten feed is similar to that of *Lambert et al.* [12].

For each of these setups, the water circulated in a closed system that alternated between the aquariums, trays of duckweed, and canisters. Polluted water from the tank was fed through trays of duckweed that acted as a filter for various organic wastes, including ammonia, nitrate, and nitrite. For physical waste, canisters were set up to capture and filter out the various pollutants.

a) The first included two tanks: Tank A and Tank B. As seen in Figure 1, water in Tank A was only filtered with a commercial filtration canister (API Filstar XP-XL). The only food supplied was store-bought aggregate fish food (Tetra: TetraCichlid Flakes or Tetra: TetraCichlid Floating Cichlid Sticks).

   As seen in Figure 1, water in Tank B was filtered with both a commercial filtration system and trays of duckweed. The fish were fed with commercial fish food equivalent to 1.5% of their total weight. Two-thirds of the total feed came from the commercial feed, and one-third came from duckweed.

   Fish biomass started at 1.5 grams each and ended at 470 grams. Each tank held between 5 to 10 fish each throughout the experiment, and we routinely readjusted the food quantity and type as the fish grew larger. Water quality and fish weight were regularly measured, where each weight measurement consisted of two randomly selected fish whose scale readings were averaged. Both tanks were given appropriate care and cleaning to ensure as low a stressful environment for the fish as possible. The primary purpose of using Tanks A and B was to prepare for the actual study involving Tanks C1, C2, D1, and D2.

b) The second system included 4 identical tanks, and its setup was based on what we learned from the first system.

As seen in Figure 2, water in Tank C1 was filtered by commercial filtration canisters (API Filstar XP-XL). The fish were fed commercial fish feed and duckweed in a 1:3 ratio. We used the dry variety of duckweed at first, and around halfway through the study, we switched it out with wet duckweed (we assumed dry weight is 10% of wet weight).

Water in Tank C2 was filtered both by commercial filtration canisters and by the duckweed trays. The fish in C2 were fed commercial fish feed and duckweed in a 1:3 ratio. Similar to Tank C1, we used the dry variety of duckweed at first, and around halfway through the study, we switched it out with wet duckweed.

Water in Tank D1 filtered by both commercial filtration canisters and duckweed trays. The fish in D1 were fed only commercial fish feed.

Commercial filtration canisters filtered water in Tank D2. The fish were fed only commercial fish feed.

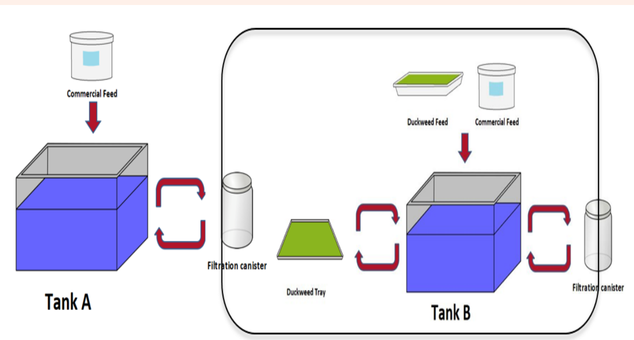

Figure 1: Setup for the first experiment. denotes the aquarium; denotes duckweed feed; denotes commercial feed; and denotes the commercial filtration canister notation denotes water circulating between the two parts, and the arrow denotes the feed placed in the aquarium.

Similar to the first system, we routinely readjusted the food quantity and type as the fish grew larger. In addition to a weight measurement, we also measured the parameters pH, Alkalinity, Hardness, Chlorine, Ammonia (NH_3), Nitrites (NO_2^-), Nitrate (NO_3^-), and O_2. While the system stabilized, we measured each parameter daily. Afterward, measuring was done every other day for 14 days. Following the 14-day period, parameters were measured once every 4 days. However, if any of the fish were observed to change in appearance/behavior (agitation, rough scale appearance, fin deterioration, rapid gill excursion, and change in the quality of redness in gills), immediate measurement of the parameters was conducted. Each weight measurement consisted of two randomly selected fish whose scale readings were averaged. Tanks were given appropriate care and cleaning to ensure as low a stressful environment for the fish as possible. This care included changing 10% of each tanks' volume weekly, maintaining a temperature range in the tanks between 24 - 27 degrees Celsius.

Both systems had two types of duckweed filtration systems.

a) In system 1, the water level of the fish tank and duckweed trays were equivalent. Water was pumped out of the tank and into the duckweed trays, and another pump cycled it back into the fish tank. This process was repeated twice a day for thirty minutes. This process is denoted as DPM1.

b) In system 2, the filtration system using duckweed was performed using gravity. There were three trays set vertically where the top tray was lower than that of the aquarium's surface water. Gravity moved the water from the first tray to the second to the third. A pump at the bottom sent the filtered water back into the aquarium. The advantage of this duckweed filtration type was that it was constantly working for all hours of the day without the need to turn the pumps on and off. This process is denoted as DPM2.

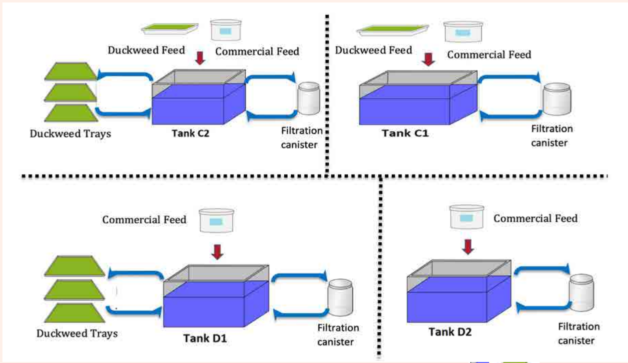

Figure 2: Experimental setup for the second experiment. denotes the aquarium; denotes duckweed feed; commercial feed; denotes the duckweed filtration system; and denotes the commercial filtration canister notation denotes water circulating between the three parts, and the arrow denotes the feed placed in the aquarium.

Calculations

For this project, the data is broken down into six subsets: Aquarium A, Aquarium B, Aquarium C1, Aquarium C2, Aquarium D1, and Aquarium D2. Each one of these subsets has undergone a different treatment. The dependent variable is the fish's weight, which mainly affected by the amount of feed that the fish received, albeit the ammonia levels were on average lower in tanks connected to duckweed trays.

The experiment's structure was such that only the amount of feed (wet duckweed, dry duckweed, commercial feed) and temperature were recorded daily. The fish's weighing was done at a semi-regular level, with the smallest interval between weighing being two weeks. Pollutants were measured twice a week.

The thought process in creating the panel data was to determine a way to compile the data in such a way that fish-weight would the dependent variable. The variables concerning feed were cumulatively added up from the initial time period to the time where the feeding took place. For example, the wet duckweed variable for the 2nd fish weighing at time t = 100 was the sum of wet duckweed feedings from t = 1 to t = 100. This process was repeated for wet duckweed, dry duckweed, and commercial feed. For the remaining variables, the data were averaged in – between the time of weighing. For example, the ammonia level corresponding to the 2nd weighing at t = 100 was the average of the ammonia levels recorded from t = 50 + 1 (t = 50 being the time of the 1st feeding) to t = 100.

In generating these values, we first determined the number of weightings that occurred for the specific tank. This was done so to determine the number of observations that would be recorded for that specific tank. Based on the k number of weightings recorded, a column of k length was created with each column's row to contain a weighing value. Next, we summed the feeding variables' values (dry duckweed, wet duckweed, commercial feed) and concatenated them in the order of their respective weightings. For the remaining variables (pH, Alkalinity, Hardness, Chlorine, Ammonia (NH_3), Nitrites (NO_2^-), Nitrate (NO_3^-), and O_2), we averaged each of the variables over each time step. The dependent variable we are trying to find is the weight of the fish, which has shown to be mainly affected by the amount of feed that they received, albeit the ammonia levels were on average lower in tanks connected to duckweed trays.

The experiment's structure was such that only the amount of feed (wet duckweed, dry duckweed, commercial feed) and temperature were recorded daily. The fish's weighing was done at a semi-regular level, with the smallest interval between weighing being two weeks. Pollutants were measured twice a week. The averages of each variable between weightings were calculated and concatenated into their respective columns. Each row of each column represented the average of the variable for that time interval. After all the variables were added, every variable and its corresponding column vector were concatenated together. The final table had columns representing every variable and rows representing the average of the variables for their corresponding time interval between weightings.

The data collection process was repeated for every tank. The six data sets were merged into one unified panel data set.

For the project's data analysis portion, several new variables were created to help with the modeling. The first of these variables was a dummy variable named "DPM1." A non-zero value of DPM1 indicates the usage of the pump method of water circulation in the aquarium system. The next variable was "DPM2." A non – zero value of DPM2 indicates the usage of the gravity circulation in the aquarium system. The next variable was the dummy variable "DPM," which is the sum of "DPM1" and "DPM2". A non – zero value of DPM indicates the presence of a duckweed filtration system in the system. The next variable created was the "feed" variable. The "feed" variable is the sum of 10 percent of the wet duckweed, the dry duckweed, and commercial feed. The wet duckweed was multiplied by 0.1 due to much of its mass being comprised of water and not actual nutritional substance. The last variable created was the LW variable, which was the natural log of the weight of the fish.

Theory

In presenting the methodology, we let each β_i represent a coefficient of its corresponding independent variable x_{it} for aquarium i at time t. The parameter β_i explains how a change in x_i affects the dependent variable, in this case y, where y is the log of the weight of the fish. The log of the fish's weight is taken primarily to linearize the weights. Because the dependent variable has been transformed with a log, and all of the explanatory variables remain level, a 1-unit change in x will result in a β x 100% change in weight.

The experiment's nature results in every observed tank possessing time-invariant characteristics that are unique to that plant. An effective way of accounting for these unique characteristics is through panel data [13], which can control these differences and result in efficient and consistent estimates. The low number of observations for some of the tanks is another reason to employ panel data techniques. Panel data techniques allow us to combine the various tanks' data into a single dataset, thus avoiding a small-sample size pitfall. This is only possible if the individual tanks' inherent characteristics were time-invariant, which, fortunately, they are. Thus, to determine the values of the coefficients, we move to panel data models.

We focus on two types of panel data models: fixed effects and random effects. While technically both types can be applied to any dataset, incorrect application results in inaccurate conclusions.

A fixed-effects model is used when one believes that the unobservable variables are correlated with the observable variables. The fixed-effect model (Eq. (1)) uses each subject (in this case, fish tanks) as their own controls by holding the effects of these unobservable variables "fixed," as the name suggests. In a fixed-effects model, these unobservable effects are broken into two parts: one part that represents the characteristic traits of each tank (α_i), and a second part that represents white noise (ϵ_{it}); that is,

$$y_{it} = x'_{it}\beta + \alpha_i + \epsilon_{it} \quad (1)$$

The parameters of the model which we estimate and are of interest are the vector β.

A random-effects model is used when one believes that the unobservable variables are either uncorrelated with the explanatory models and/or there are no omitted variables (variables left out of the modeling equation that affect the dependent variable). A random-effects model will still use all the data available, and produce smaller standard errors than a fixed-effects model. In a random-effects model, the unobservable effects are represented by an error term, and both the intercept ($\alpha_i=\alpha+\mu_i$) and error term (ϵ_{it}) are independent random variables. The model itself can be represented by

$$y_{it} = x'_{it}\beta + \alpha + (\mu_i + \epsilon_{it}) \quad (2)$$

Let α be the regression constant, μ_i is a random variable specific to the i^{th} tank and is constant through time, and ϵ^{it} is the idiosyncratic error term. In what follows, let $\zeta_{it} = \mu_i + \epsilon_{it}$.

To determine which model is better (fixed or random), we use the Hausman Specification Test [14]. The test compares an estimator that is consistent with an estimator that may or may not be consistent but is efficient. In this case (panel data), our consistent estimator is the fixed effects model, and our efficient but not necessarily consistent estimator is the random model. In this case, the null hypothesis is that the random-effects model, in addition to being efficient, is also consistent. The Hausman test checks this by comparing the two models' coefficients; if the random-effects model is statistically similar to the fixed-effects model, then the null is true, and the random-effects model is both consistent and efficient.

After running the Hausman test and determining the best model, we estimated the coefficient values to give us the optimal combination of accuracy and precision.

Results

First, we analyzed and evaluated the effect of duckweed on fish growth. In this model, y_{it} is the log of the weight of the fish in tank i at time t, x1t is the total feed supplied to the tanks measured in grams in period t, and x_{2t} is the total duckweed supplied to the tanks at time t. The estimation results are depicted in Table 1.

After conducting the Hausman Test with a null hypothesis claiming that both tested models are consistent, we were returned a p-value of 0.789. Therefore, we fail to reject the null, and assume that the consistent and efficient estimates are those estimated through the random effect model.

Table 1: Commercial versus duckweed feed.

	Random Effects (Standard Error)	Fixed Effects (Standard Error)	OLS (Standard Error)
Constant	3.55		3.59
	(0.14)		(0.11)
Total Feed	0.012	0.012	0.011
	(0.0018)	(0.0019)	(0.0019)
Duckweed Feed	0.009	0.00011	0.0014
	(0.0099)	(0.011)	(0.0092)
N	32	32	32
R2	0.83	0.83	0.78
Adjusted R2	0.81	0.8	0.77

From our model, we can infer several conclusions. Chief among them and perhaps most importantly, is the importance of feed biomass and the insignificance of its source, i.e., commercial or duckweed. The analysis statistically supports the claim that duckweed via weight is a good substitute to commercial feed when focusing on the fish's growth rate. This thus implies that so long as the percentage of duckweed feed does not rise above 40% of total feed (the highest levels we reached in this study); fish growth will not be impeded. The growth curves of Tank A versus Tank B (Figure 3a), as well as Tanks C, C2, D1, and D2 (Figure 3b) are depicted below.

The Red-Belly Pacu fish's growth curves do not present substantial differences among fish feeding duckweed versus those whose diet is only commercial feed.

From the data in this experiment, we find that the fish growth rate gradually increases as the fish themselves increase in size. While the data collected during this experiment never measured the point at which the rate of the growth rate started to decrease, we continue to grow the fish and leave this to future research. For more on fish growth models and their implications, see *Hopkins [*15]. In this paper, Hopkins describes various ways to model a fish's growth rate, with the Von Bertalanffy Growth Functions being the most commonly used that can rely solely on fish weight.

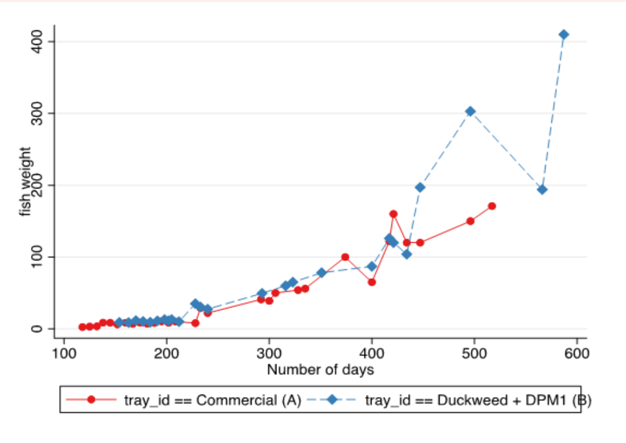

Figure 3a: Tanks A & B.

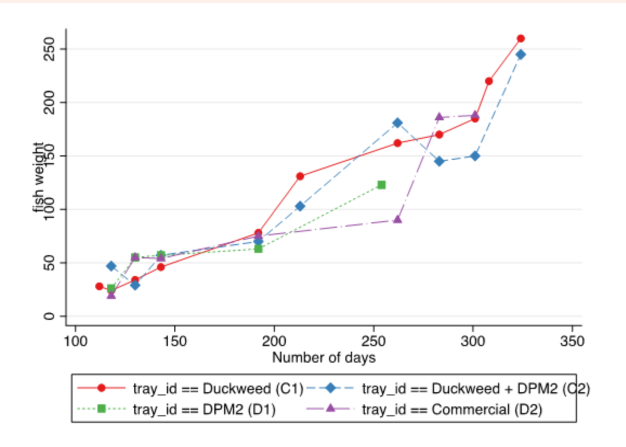

Figure 3b: Tanks C1, C2, D1, & D2.

Figure 3: Fish growth over time. Figure 3a depicts the growth curve of tanks A and B, while Figure 3b depicts the growth curve of tanks C1, C2, D1, and D2.

Ammonia levels and its effect on fish growth: To understand the second hypothesis regarding ammonia levels and its effect on fish growth, introduced the level of ammonia measured in each tank in parts per million (ppm), where x_3 is a dummy variable to equals 1 in the presence of a Duckweed filter system (DPM2) and 0 otherwise. The estimation results are depicted in Table 2.

After conducting the Hausman Test with a null hypothesis claiming that both tested models are consistent, we were returned a p-value of 0.977. Therefore, we fail to reject the null and assume that both models are consistent but that the random effect model is the efficient model.

From this regression, the sign of the marginal effect of the interaction variable of filter and ammonia is positive, albeit not significant. To this end, *Porath and Pollock* [16] showed that duckweeds serve in an aquaculture system as an ammonia stripper. Those authors' analysis showed that "In an axenic culture of 0.1–0.3% duckweed biomass, Lemna gibba stripped 50% of the ammonia present at levels 10^{-4}M NH^3 har2: NH_4^+ in 5 h, while the nitrate level (10^{-2} M NO_3^-) remained constant. Circulation of fish effluent under a duckweed mat promoted an uptake of 80% ammonia in less than 48h."

Table 2: DPM and the level of ammonia.

	Random Effect (Standard Error)	Fixed Effects (Standard Error)	OLS (Standard Error)
Constant	3.62		3.64
	(0.15)		(0.11)
Total Feed	0.012	0.012	0.011
	(0.0014)	(0.0014)	(0.0016)
Ammonia	(0.02)	(0.02)	(0.02)
	(0.0028)	(0.029)	(0.03)
Interaction variable of filter and ammonia	0.011	0.008	0.024
	(0.04)	(0.044)	(0.038)
N	24	24	24
R2	0.86	0.87	0.81
Adjusted R2	0.84	0.82	0.78

When depicting the ammonia levels in tank A versus tank B, ammonia levels in tank A were overall above those of tank B (Figure 4a). Similarly, when depicting ammonia levels of tank D2 versus D1 (Figure 4b), we see that ammonia levels in D2 were overall above those in D1. In both cases, the DPM was connected to B (DPM1) and D1 (DPM2), while both A and D2 had no duckweeds, the fish were fed only commercial feed, and the filtration system does not include a DPM.

Discussion and Policy Implications

From our results, we conclude that the addition of a commercial feed substitute in the form of duckweed is a viable alternative to traditional feeding methods, conditional on certain criteria. These criteria include the percentage of commercial feed replaced by duckweed and the species of duckweed used. We have sufficient proof to support the second hypothesis; the addition of duckweed to partial substitute commercial feed does not negatively impact the growth of fish compared to a pure commercial feed diet. Because of this substitution of feedstock, one can save 15% to 20% of the traditional production costs associated with raising fish using aquaculture technologies.

The data generated through the two experiments resulted in the sign of the parameters measuring the effect of duckweed on ammonia levels being negative and in figures depicting lower levels of ammonia in tanks exposed to duckweed through DPMs and/or feed. This work offers some evidence for the argument that the presence of duckweed reduces the level of waste in the water and strips the water from ammonia. In future work, we plan to build a new system and use the new systems to determine whether the first hypothesis can be proven or disproven.

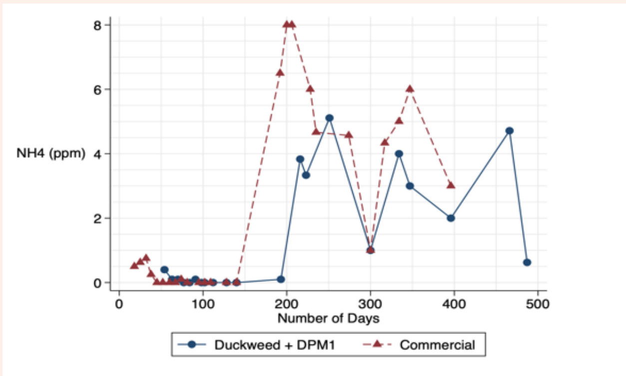

Figure 4a: Tank A versus Tank B.

These technologies, if implemented, will likely result in profitable fish to be grown under cost-saving conditions. The fish waste produced provides nutrients for the duckweed to grow as a positive externality, which in turn feeds the fish and continues the cycle, or more broadly, creates a circular economy system in which waste is reused while providing resources for the project [17]. Thus, farmers would spend less money on commercial feed for the fish since duckweed can be replaced up to a 1:3 ratio with commercial feed. Additionally, farmers would save money on nutrients needed to grow the duckweed, which will be satisfied by nutrients in the fish waste. In future work, we plan to investigate whether farmers need not spend as much on cleaning materials, as duckweed may be useful in clearing up ammonia and other waste that pollutes tanks.

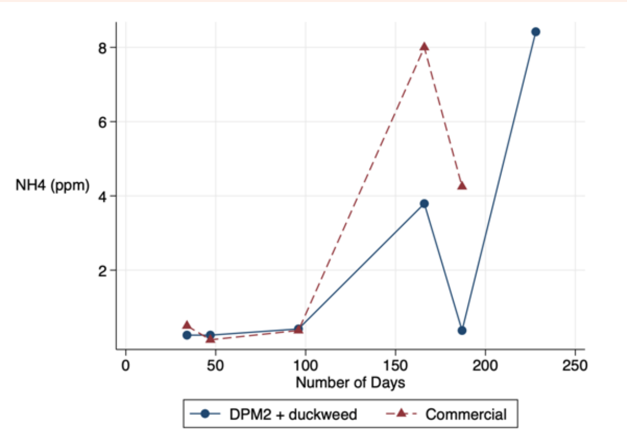

Figure 4b: Tank D1 versus Tank D2.

Figure 4: Ammonia levels in the aquariums: Comparing systems that used the DPM and those that did not (i.e., Tank B versus Tank A; Tank D1 versus Tank D2).

The regulator may consider implementing a Pigouvian tax or another similar model to increase this aquaponics system's adoption rates. In this case, the regulator can levy the Pigouvian tax on the negative externality of pollution produced at aquaculture farms through the polluted water the system discharges. Since this is a tax on pollution, farmers will be incentivized to reuse this pollution by utilizing the aquaponics system to avoid or reduce the amount they will be paying in tax [5]. By doing so, not only will the amount of pollution and waste being released into the environment reduce, but the individuals will also benefit in terms of paying less in taxes and adopting the sustainable technologies that, in turn, reduce the amount farmers will pay for fish feed and make the production more cost-efficient.

By reducing the barriers of entry, individual growers would bear less risk in adopting the system. The USDA National Program 106 from the Agricultural Research Service focuses on improving the efficiency, sustainability, and quality of aquaculture farms. It specifically relies on research involving salmon, catfish, and hybrid striped bass. If this program is modified to subsidize the individuals' investments in the aquaponics system, Red Belly Pacu need not be the only fish tested. Fish from the north, south, and throughout the country can be used to see whether this technology provides the same benefits as it did with Red Belly Pacu.

There are other existing policies in place that can increase the knowledge and expansion of these technologies so that farmers can benefit from saving 15-20% of their expenses and consumers purchase quality fish that requires fewer resources to grow. However, for the widespread use of the aquaponics system to work, expertise in both hydroponics and aquaculture is necessary. This would result either in a significant increase in the amount of money farmers would have to pay to get the system up and running by hiring specialists or the number of education farmers would require implementing the systems themselves. To avoid the extra expense of needing to hire specialists to aid farmers in implementing these technologies into their own farms, regulatory policies must allow further studying of these technologies, help understand their applications and spread this newfound knowledge and resources across the nation through extension services. A related program is from the National Institute of Food and Agriculture, which aims to improve aquaculture technologies. In addition to funding research, the NIFA has Regional Aquaculture Centers and an Interagency Working Group (IWG) that study and report various topics about aquaculture. With these groups' help, a better understanding of the aquaponics system and how it affects different farms across the US can be reached. Problems could arise while the system is being tested on different farms, so it is crucial that the IWG simultaneously works to prevent and find solutions to them. If policies from the USDA and NOAA were utilized, these technologies could be piloted with farmers, while ensuring they are properly understood and used correctly.

This technology is suited for small-scale farms, and would be an efficient addition to urban aquaculture. It is important to mention that urban agriculture and aquaculture are by no means to replace traditional farming. Rather, it is a means of utilizing city space that may have previously been deemed as unusable to provide communities with local crops (and in this case, fish) [4]. Building rooftops have a beneficial environment for the aquaponics system, as they can be more controlled than vast acres of agricultural space. The plants grown by the system will also benefit by utilizing the cities' increased CO_2 levels compared to rural areas, for greater photosynthesis rates [4]. Solar panels can replace standard nonrenewable energy sources as a provider of renewable energy for a building's electricity needs as well as the aquaponics system's electricity needs. The crops and fish grown by the environmentally friendly, chemical-free aquaponics system can be sold at higher prices [18]. This, combined with our study's findings that duckweed may replace up to 40% of commercial feed for fish, can alleviate some of the economic pressures that may arise while maintaining such a system. In the same process, unemployment rates of cities may decrease, as people will be needed to make sure the rooftop systems are under the optimal conditions for fish and crop production. The USDA's newly enacted Office of Urban Agriculture and Innovative Production provides grants to subsidize the costs of both planning and implementing aquaponics, hydroponics, aquaculture, and other types of agriculture that can be used in an urban setting . Projects for low-income communities are given priority, as they are the communities that will most benefit from such systems that provide them with a healthy source of food. In addition, grants can help provide education as a sort of extension service to farmers and communities implementing urban agriculture.

Conclusion

As seen from our data, we have determined that using duckweed as a part of Red-Belly Pacu's food source is a viable alternative to using only commercial feed. The extent to which farmers can save money by using this alternative is calculated to be 15-20%. However, in this study, we tested the duckweed and commercial feed combination in a 1:3 ratio (not allowing the duckweed portion to rise above a maximum of 40% of the total diet). Future studies can use our methods and data to test a higher percentage of duckweed in the diet. From this, we can learn whether duckweed, at a higher percentage, impedes or does not impede fish growth. This could lead to a greater calculated amount of money that farmers can save when they use duckweed as feed.

In this study, Red Belly Pacu fish were grown in tanks and fed commercial feed or a combination of commercial feed and duckweed. Future studies may focus on a different species of fish, such as Striped Bass. This could tell us whether our results can be generalized to many different species of fish, or whether our results can only be used for Red Belly Pacu fisheries. It is important to note that modifications must be made when using other species, depending on the species' traditional growth rate, size, regular diet, and other factors. The regular diet of the fish is especially important when considering using duckweed as feed. Red Belly Pacu are herbivores, so duckweed can easily be implemented. Omnivores, however, may require less duckweed than herbivores due to their nature. For carnivores, using duckweed may not be viable. We have also planned to use seaweed in future studies, rather than duckweed, to test whether it too can be utilized as a source of feed.

Circular economic technologies such as the system used in this study need not be used solely for experimental purposes. The economic and environmental benefits of implementing the system into small-scale farms or urban settings prove that this is a win-win situation [4,17], among many others). Consumers would gain access to both fresh fish and crop produce from local sources. Farmers would earn a profit from the farmed goods and lower fish feed costs by utilizing plants like duckweed. Extension services can bring education about these technologies to farmers and regulators may levy a Pigouvian tax or subsidize individual investments to promote and expand the systems. In terms of the environment, the circulating nature of the technologies allows for less pollution and waste to enter the system's surroundings and reduces the area's ecological footprint.

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