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Understanding Aquaculture and Aquaponics General Operational Parameters and Attitudes Towards Value-Added and Value-Recovered Products—Surveying Current and Former United States Midwest Cold Climate Producers

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Abstract

With the global population projected to continue to increase, the necessity for food security (i.e., a region's ability to reliably provide food to its residents) becomes ever-present. Aquaculture is currently one of the most prevalent methods for propagating aquatic species, though aquaponics (i.e., combining aquaculture and hydroponics to artificially propagate aquatic species and plants) is often considered a more sustainable food production method in comparison. Though aquaponics is promising both environmentally and socially, the general aquaponics business model is failing to generate proper revenue in many instances. The addition of value-added and value-recovered processes is one option for producers to increase the value of their final products without major capital investment. A paper survey was deployed for this study for both aquaculture and aquaponics operations, given the current prevalence of aquaculture and infancy of aquaponics in the United States. The survey aims to understand the basic parameters of their operation while also gauging interest in the addition of value-added and value-recovered products for their operations. Less than half of the respondents were interested in value-added and value-recovered products for several different reasons. The survey also provides useful information related to operation, prior experiences, and potential future directions for aquaponics in the United States, though investigation into consumer preferences is required for optimized success of the aquaponics industry.

Keywords: aquaculture producers; value added products; value recovered products; sustainability

1. Introduction

Aquaculture arose as a viable alternative to industrial fisheries, given the stagnation of industrial fisheries total harvests [1]. Industrial fisheries utilize several different kinds of technologies to efficiently harvest wild-caught aquatic species, while aquaculture utilizes tanks or netting and feed to artificially propagate desired aquatic species [2,3]. The farming of these species is required to answer the ever-increasing global demand for aquatic species, given industrial fisheries would need to travel further out into seas and oceans to find new populations to harvest, which would in turn increase the price of seafood for the consumer. Globally, aquaculture generates hundreds of billions of dollars annually in sales, making this part of the food sector highly lucrative from an economic perspective [1]. Aquaculture has proven to be effective in reliably propagating large quantities of aquatic specimens in relatively small volumes of water, however, this food production method also brings many negative considerations and consequences along with it. First, aquaculture currently depends heavily on forage fish (i.e., small, wild-caught prey fish), which is growing more

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unsustainable as aquaculture production continues to increase while again industrial fishery harvests have largely remained stagnant for some time and the growing concern of ecosystem disruption for the wild life remaining in the oceans [4,5]. Second, aquaculture operations output nutrient dense effluent water and is currently considered a waste stream, causing further concern for consequences such as eutrophication (i.e., nutrient runoff which collects in waterways and causes algae blooms and weeds) [2,6]. Because demand for aquatic species continues to increase and the downsides related to aquaculture, other alternatives are essential for more sustainable food production.

Sustainability is the amalgamation of economic, environmental, and social considerations for products and processes, where the goal is to minimize environmental impact while maintaining proper profit margins and consumer demand. As discussed earlier, aquaculture leads to several environmental concerns, leaving significant room for improvements when considering sustainability, making aquaponics a reasonable food production alternative. Aquaponics uses a symbiotic relationship between aquaculture and hydroponics (i.e., generally a water-based method for growing plants) for the purpose of using the outputs produced in aquaculture to hydrate and fertilize the plant production section which then acts as a natural nutrient filtration system for the fish tank [7–9]. This food production methodology has proven to be effective in reducing waste streams and water use when compared to aquaculture [10]. Though promising on some fronts, aquaponics can be energy intensive and conventional fish feeds are also commonplace [7]. As renewable energy and alternative feeds are being investigated, ensuring a stable industry and market in the meantime, is critical.

While aquaponics is becoming increasingly popular in the United States (US), many venturing into the aquaponics industry seem to be floundering with the general business model under the current economic system, especially in light of the recent pandemic [11]. Love et al., (2014) conducted an international survey of aquaponics practitioners which investigated baseline operational information. For example, plant and fish types, annual harvest quantities, purpose of the operations, facility information, energy sources, and more were collected to better understand the overall landscape of aquaponics globally [12]. The authors found that many of these operations were small-scale hobby projects, showing interest for this type of food production, but they also do not have the necessary tools to scale-up the operation to make it into a formal business [12].

In another related paper by Quagrainie et al., (2018), a comprehensive economic analysis of hydroponics versus aquaponics in the Midwest (a region in the US) was conducted and a separate analysis of three different scales of aquaponics operations was also conducted to better understand the current financial landscape of the industry in that region and the repercussions of choosing a certain scale of operation. The authors investigated four active operations along with conducting a literature review of other operations analyzed in published work [11]. The authors found that the largest farm tended towards more consistent success due to lower production costs (i.e., economies of scale), however, with proper operational choices, such as certified organic plant production, most aquaponics businesses can be successful in the Midwest. The authors identify limitations of this work as having no consideration for distribution and marketing, two crucial factors for a fruitful business in the US. Though production is a major aspect of an aquaponics operation, sales and distribution are other major considerations relative to overall business success in the industry.

Since economic success can be difficult to bring to fruition in the aquaponics industry, the use of value-added (VA) and value-recovered products (VRPs) has been proposed to help stimulate revenue generation and increase potential for more stable product distribution. Valueadded products (VAPs) are produced using post-harvest processes (e.g., smoking, dehydration, freezing techniques, etc.) to make the final distributed product more valuable. VRPs are produced using operation by-products or waste streams and performing processes (e.g., drying, grinding, digestion, etc.) to make a valuable product. Several studies have investigated options for byproducts produced in aquaponics. For example, Shahidi and Ambigaipalan, (2015) discuss the many different substances and products that could come out of seafood byproduct. They discuss omega-3's, chitin, collagen, protein, vitamins, and more as several options for valuerecovered products for the purpose of describing the nuance of each one, how they could be used and discussed where these substances

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would come from relative to seafood byproducts [13]. However, the authors do not consider the viability and economics of said products or the processes to make the products and no other study exists investigating VA and VRPs in the aquaculture and aquaponics industry, requiring further investigation.

The goal of this study is to investigate cold climate aquaculture and aquaponics operations' general operating parameters as well as quantify their willingness to invest in the addition of value-added and value-recovered processes to their current operations using a survey.

2. Methods

While the survey conducted by Love et al., (2014) was thorough in gaining a periphery understanding of many operations across the world, the survey did not consider certain noteworthy areas, such as distribution decisions and gauging interest in VAPs and VRPs. Literature into current and former aquaculture and aquaponics operations is somewhat limited, but investigation into US cold climate operations is even more so, making the survey a fruitful endeavor.

The main country of focus was the US as investigation into aquaponics sustainability is extremely limited and interest in the methodology is increasing. US cold climate operations were specifically the target population for the survey as these operations have an additional layer of complexity given the higher dependence on energy (from increase heating and lighting demands) for the cold months of the year, which is an additional expense for these producers to consider, particularly Wisconsin, Minnesota, and Michigan, given the interest in local impact and the ease of access to permits and thus mailing information. The survey was approved by the University of Wisconsin – Madison Institutional Review Board (ID: 2023-0285). Informed consent was described at the beginning of the survey and was assumed if the respondent completed and submitted the survey and was only applicable for adult producers. Aquaculture producers were also included in deployment for multiple reasons. First, aquaculture producers with already intensive (i.e., dedicated tanks for propagation) operations could transition to aquaponics, making it an interesting avenue to explore in the survey. Lastly, though the plant side of aquaponics is generally more fiscally productive (some waste from plant production can be produced but is generally sporadic and minimal), one of the main waste streams leaving these systems (aside from the effluent water and solids) are the carcasses produced by the fish, making their opinion and interest in value-recovered products equally valuable. Mailing paper surveys was the main mode of deployment, given the information available from the licenses, however, the survey was also made into an online version to be distributed using social media to ensure minimal operations were missing in the three states.

The initial part of the survey was developed using the support of the survey deployed by Love et al., (2014), given the lack of standardization of surveys in the aquaculture industry. The survey consists of eighty-three total questions with separate sections for aquaculture and aquaponics operations (full survey instrument in SI). The first and third sections of the survey ask questions related to overall operational information for aquaculture (first section) and aquaponics (third section) operations. General operation questions were posed (e.g., types of fish, annual harvest amounts, distribution methods, changes to their operation over time, etc.) to gain some interesting parameters so comparisons can be made amongst all respondents. The general information section also allows for analysis to include the exploration trends relative to financial success as well as allowing for a better understanding of potential external factors which would make the producer more inclined to make changes to their operations or achieve overall success. Other lesser components (e.g., impact of a pandemic) are also contained within this section and will be discussed further in the subsequent sections.

The second section explores interest in aquaculture producers transitioning to aquaponics operations, which aims to understand potential interest in transitioning into aquaponics, any potential challenges related to the transition, and quantifying the rate of return these producers would like to see if they were to make the transition.

The fourth section examines producers' willingness to invest in the addition of valueadded and value-recovered processes for the purpose of making their final product more valuable without requiring high capital investments. The section initially investigates how the operation's products are currently sold and asks about VAPs and VRPs that have already been considered by producers and the potential challenges with these post-harvest processes. Questions related to willingness-to-invest in VAPs and desired product characteristics from a producer's perspective were also posed.

The fifth section surveys the producers themselves. This section aims to understand previous education and experience related to agriculture. The purpose of this section is to gain some insight into how previous education and experience can impact an aquaculture or aquaponics operation and its success. The final section collects some general demographic information to understand any trends related to considerations such as age, gender, or region and their potential relations with choices in fish types, distribution method, etc.

3. Results & Discussion

The purpose of this study is to gain insight into aquaculture and aquaponics as a business venture and assess producers' attitudes towards value-added and value-recovered products. Three hundred and eighty paper surveys were deployed 05/05/2023 to aquaculture license holders in Wisconsin (one hundred seventy-nine), Minnesota (one hundred twenty-six), and Michigan (forty), with an online version being published 05/05/2023, and closed 07/25/2023. Based on investigation into the license holders, twenty-five operations in Wisconsin, one operation in Michigan, and nine operations in Minnesota are likely aquaponics operations. After working through address corrections and other errors, eight paper surveys could not be delivered for various reasons. Three paper surveys were returned, and four emails were received from those who did not wish to take the survey, or the survey was not applicable to them.

From the deployment, forty-seven total responses were collected, mostly from the distribution of the paper survey. Due to incomplete responses or inadequate information given, only twenty-five were able to be analyzed and compared. Of the twenty-five responses, twentythree were from aquaculture producers and two were from aquaponics producers.

3.1. General Operational Background Information Section

The goal of this section is to better understand the different factors and constraints under which these producers are working. Exploring years of operation was one of the necessary bases of the survey and this section to better understand the age of the industry in the region and is established in Figure 1. Figure 1 shows the surveyed operations have been/were in business for a wide variety of time, with "21-30 years"

Another point of interest in the survey was to better understand the original purpose and motivation of the operations. Figure 2 shows the original purpose of the surveyed operations, with "financial gain" being the most selected option (fourteen) and "self-sustaining lifestyle" being a close second at thirteen times selected. Wanting a challenge and "education" were the two least selected options. Another question asked in the survey was similar to the previous one but was meant to draw more distinction relative to their motivations (Table A in SI). The highest motivators were "economic benefit" (six), "grow your own food" (six), and "improve community food security" (five). Interestingly, "economic benefit" was also one of the lowest ranked motivators for five operations. Figure 2 and Table A illustrate these producers' desire to turn profit, while also working to benefit both themselves and their communities, which further emphasizes the necessity for additions such as VAPs and VRPs for these operations.

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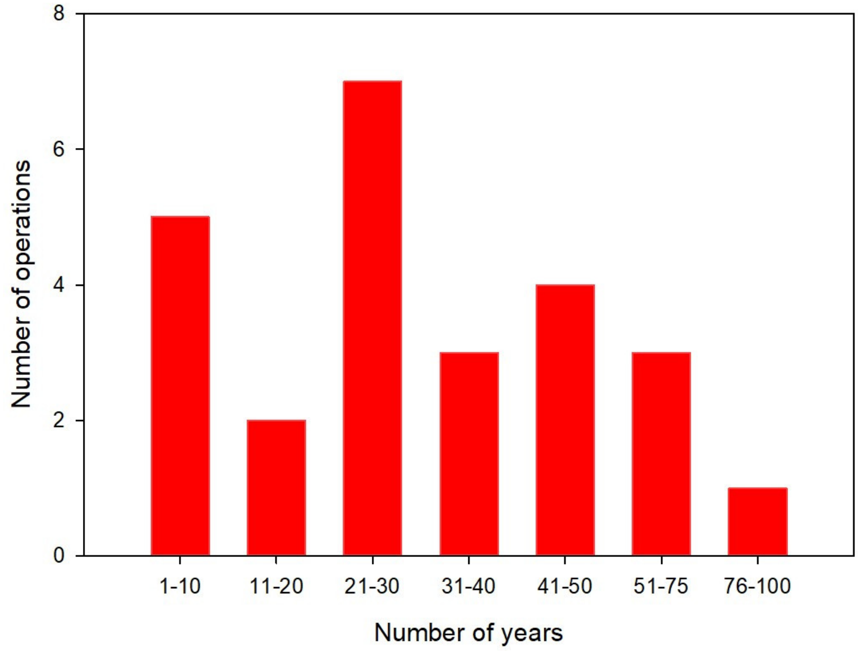

Figure 1. Years of operations for surveyed producers, including closed operations in operation being the most common and "76-100 years" being least. The figure shows the relative success in terms of time for these operations, though three aquaculture operations are no longer in operation for various reasons. One operation was seemingly forced to close due to a loss of equipment because of a missed loan payment, while another struggled to sell their product in general. The causes for closure of these operations are all within the confines of reason, though the value-added and value-recovered products are aiming to help avoid these failures in the future. Both aquaponics operations were in the "1-10 years" range (one of the operations is also no longer in operation), expressing the relative infancy of aquaponics in these states.

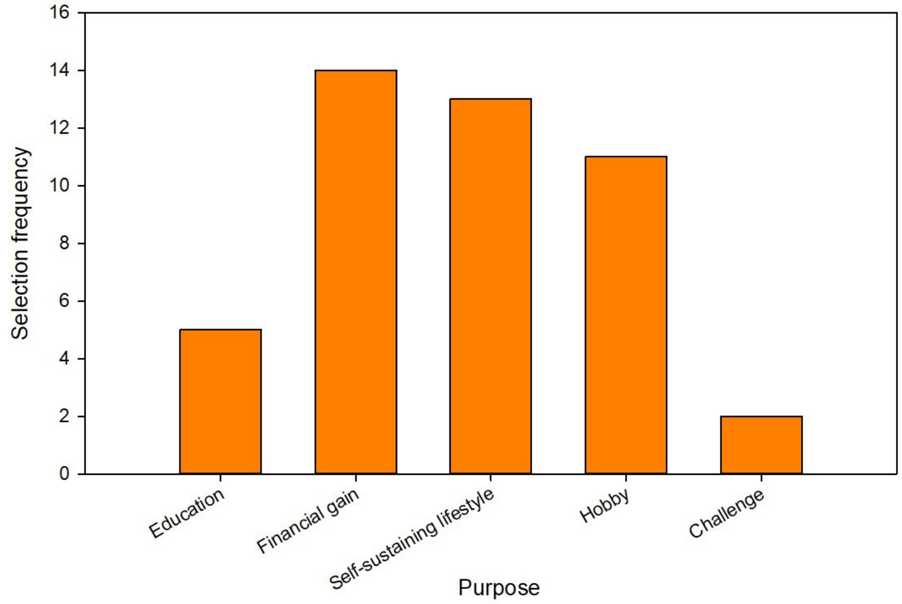

Figure 2. Original purpose(s) of surveyed operations.

Following operational timeline, purpose, and motivation, delving into the particulars of the operation was the next step. For the aquaculture operations, five were intensive systems, eight were extensive (i.e., utilizing netting and waterways to farm aquatic species), and eight were a mixture of both intensive and extensive systems. In these different systems, many types of fish were propagated in the same operation, with eight operations opting to focus on one (see figure A in SI). Surprisingly, over half of the operations had two or more species being propagated, which expresses promise for success using multiple species in the aquaculture industry, given different consumers may prefer one species over the other. For example, some operations were growing fish such as catfish, bluegill, bass and others, which would imitate a particular trophic level in bodies of freshwater while also allowing the business to sell multiple products (e.g., some sold as fresh fillets, some sold for stocking, some could be processed further). Figure 3 displays the different kinds of fish grown by the surveyed operations. The two most propagated types were bluegill and trout (twelve each) with perch and bass following those, implying demand serviced by these operations is mainly for local species, though a decent variety of fish are currently being grown in cold climates (shown through the other operations). The choice of local species is noteworthy because concerns with importation permits and contamination with natural bodies of water would be largely mitigated. The choice of local species helps with reducing operating costs as these species are already acclimated to cold climates, unlike tilapia. One of the two aquaponics systems grew bluegill and lettuce, while the other grew tilapia and several kinds of vegetables and leafy greens (e.g., lettuce, cucumbers, herbs, and edible flowers). The choice of combinations by the aquaponics producers is interesting because while both chose commonly propagated fish in aquaculture, one chose a textbook type of plant (lettuce) and the other seemingly explored many different options, which allowed them to sell into a few different markets (i.e., schools, restaurants, grocery stores, and specialty shops). Further discussion will accompany harvest quantity and distribution methods.

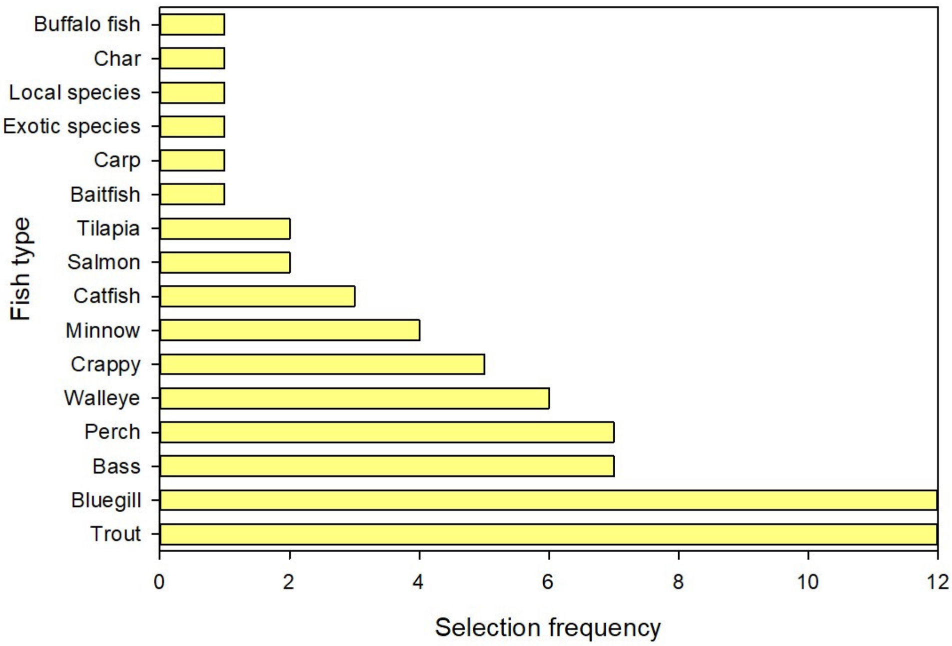

Figure 3. Types of fish propagated in surveyed operations.

Another point of exploration was the estimated annual harvests of the previously investigated fish (Figure B in SI). First, estimated annual fish harvests were highly varied amongst surveyed operations. Six operations harvest an estimated "10,000+ pounds" annually, while six produced forty-nine pounds or less. For the two aquaponics operations, their estimated annual fish harvests were both "100-499 lbs," along with estimated annual plant harvests of "100-499 lbs" and "5000-9999 lbs." The stark difference in plant harvest quantities is unsurprising given the latter operation produced many plants including vegetables. Though the plant annual harvests were vastly different, harvest quantities of the fish were similar, causing curiosity relative to nutrient cycling and stocking densities of the fish.

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How the products were prepared for sale and the distribution of the producers' products is an additional point of interest explored by the survey. First, many producers sold their fish live for the purpose of stocking local bodies of water. Other producers were propagating baitfish for stocking and recreational fishermen, while the rest were growing fish for consumption. The producers growing fish for consumption prepared for sale in different ways. Most operations sold their product as fillets directly, while one other sold their fish whole, and two others already sold VAPs. Four operations did not sell their fish either because they had a particular license where sale was excluded, or they only produced enough for their own consumption. Product types and distribution choices by these producers are interesting because choices such as selling directly can be easily disrupted when compared to selling into food services and grocery stores. Two operations already producing VAP also demonstrate some promise in the market by showing consumer interest in relevant products.

Along with current standings, the survey explored any scaling that had occurred while these operations were in business. Thirteen operations reported to have scaled up, three operations scaled down, and seven operations stayed the same. Reported challenges related to scaling include having more to manage, limitations due to regulations, and increased staffing costs. The scaling of these operations is fascinating because it shows an upward trajectory for many, which allows for reduced production costs (i.e., economies of scale) to take place.

Exploring the many challenges faced by the surveyed producers is useful for informing future ventures in the aquaculture and aquaponics industries. Figure 4 displays the many different operational challenges the respondents have had to overcome. The main issues reported were "pest problems" and "maintenance issues." One aquaponics operation reported dealing with a virus plaguing their plants. The other least selected challenges were "nutrient cycling issues" and "infrastructure issues." All these challenges are worthy of note because one ("pest problems") is largely out of the producer's control once operation begins, especially if the products are certified organic. Producers also cannot control when their operations have issues, however, regular checks and tests could help to alleviate the negative repercussions of a component failing. The set of challenges faced by the producers demonstrates the nuances of owning and operating aquaculture and aquaponics businesses, though they are not the only potential challenges.

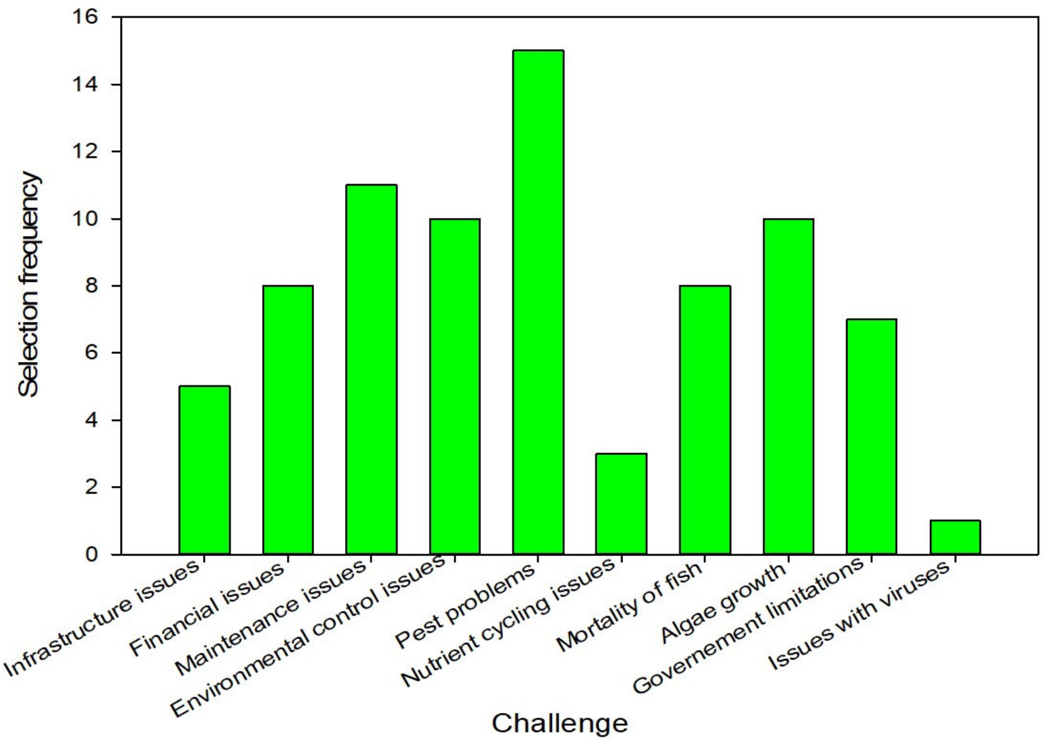

Figure 4. Operational challenges faced by surveyed operations.

Another set of challenges was realized during the COVID-19 pandemic and was explored by the survey. The pandemic was an extraordinary event which brought to light many pitfalls in many different industries. All but two operations were operating during the pandemic and the main issue reported was, unsurprisingly, the disruption of distribution and sales. The next most common responses were delayed funding/loans, their associated business shutdown, workforce limitations, and the loss of necessary equipment. The responses to this part of the survey were interesting because it showed this industry was also heavily impacted by the pandemic and showed the importance of further investigation into practical ways to prevent future disruptions.

Exploring the idea of transitioning the aquaculture operations to aquaponics was also investigated. Based on other questions, seven operations should be able to physically make the change, though more creative techniques could be used to allow all operations to be transitioned. Eight producers responded that they would be interested in making the transition. With an overall goal of sustainability in mind, aquaculture operations introducing the hydroponics section to their operation would help to mitigate nutrient loss and waste streams, while also opening a new market and revenue source to the operation with minimal effort.

3.2. Agricultural Previous Knowledge & Experience Section

The goal of this section was to learn more about the producers themselves and better understand their prior experiences related to agriculture. The first set of questions focused on the prior educational opportunities and experiences on various agricultural topics prior to the start of their operations (Figure C in the SI). The topics offered were "general agriculture," "hydroponics," "horticulture," "aquaculture," and "controlled environment agriculture." There were a wide variety of responses to this set of questions, though most respondents reported a decent amount of schooling relative to general agriculture and aquaculture. The next set of questions focused on the prior "hands-on" experiences of the respondents in various agricultural applications. Figure 5 is the culmination of the responses to these questions. The

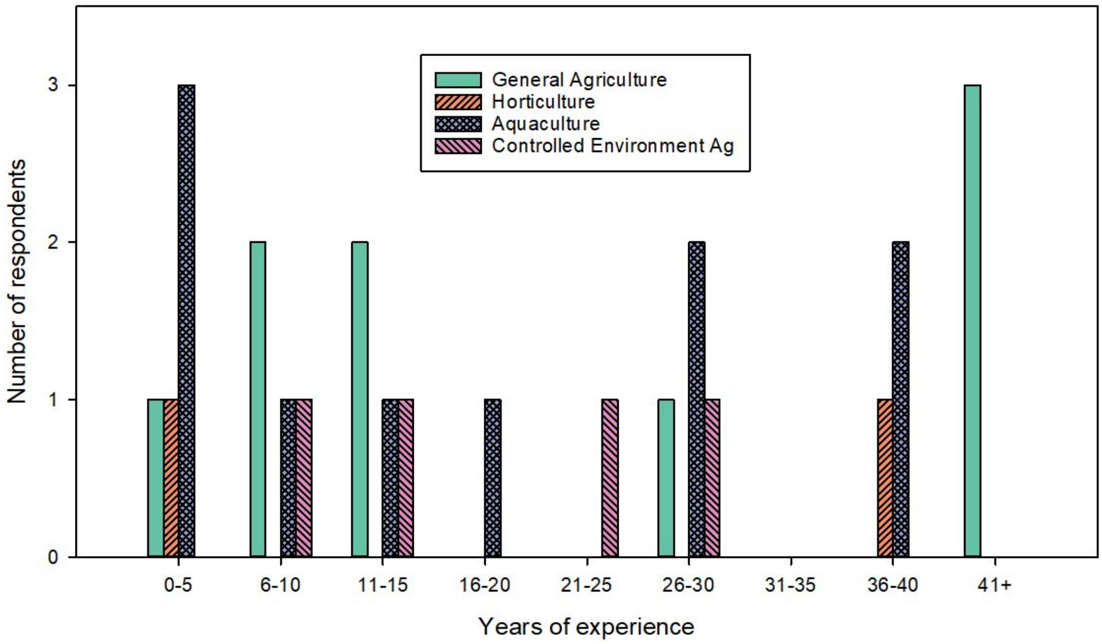

Figure 5. Prior experience gained before starting aquaculture or aquaponics business figure shows a wide array of prior experiences over a wide expanse of time. Based on the two sets of results from the section, producers seemed to have had at least some experiences around agriculture and aquaculture and some experience in other parts of the agriculture sector or with other aquaculture operations before starting/investing in their own.

Asking the opinions of the producers was essential for better understanding the resources they used and those that would have helped them when beginning their aquaculture/aquaponics operations. First, the surveyed producers reported to have used many different resources to aid in their entrepreneurial endeavors such as the use of manuals, online forums, and mentoring (see Figure D in SI). The most reported resource was simply various classes either through school or third-party organizations. Next, the producers' most suggested resource was grants offered to this industry, which will be discussed further in the discussion of permits and policy. The other two suggestions were related to an increase in relevant classes offered, which will also be discussed further in a future section. Some useful online resources for aquaponics include tutorials from Iowa State University and online forums run by The Aquaponics Association, which both help to raise the curtain on aquaponics as an operation and a business [14,15]. Schools are also beginning to recognize the utility of aquaculture and aquaponics, so parts of classes are being allotted to these subjects. Based on their responses and recommendations, these producers clearly recognized the importance of education and experience prior to their endeavors, but it is also clearly not the only factor for success in this industry.

3.3. Aquaculture & Aquaponics Value-Added & Value-Recovered Products Section

The goal of this section is to gauge interest in value-added and value-recovered products for the purpose of helping to improve the stability of general aquaponics businesses in the current market. The section explores any prior interest in value-added and value-recovered products along potential challenges they could foresee with said products. Eight producers reported to have considered producing value-added and value-recovered products, while one operation did smoke some of their product already. For the challenges, the most common responses were related to government regulations around the processes used to the products, which was also a key reason why many respondents were hesitant to invest. The other challenges reported were the need for additional employees, initial costs, and the increase in time needed. The challenges that concern the producers are reasonable, however, if done correctly, the government should not interfere given the proper permits were attained and the quality of the products is ensured.

To quantify the producers' interest in VAPs, they were asked for the desired return on investment for a VA filet (figure E in SI). The responses (seven) show limited interest of these products in general, though those most that were interested tended to have a reasonable desired extra revenue (between $2 and $12 per pound), given the general sale per pound of typical raw fish filet is anywhere from an estimated one to twenty-five dollars per pound or more depending on the species of fish [16]. Eighteen respondents either chose not to answer or answered they would not invest with any increase in revenue. The latter would not invest for multiple reasons with the main one being the old age of respondents and unwillingness to further invest in the business. Other reasons include having limited time and wanting a more stable market, which was assumed to mean having a consistent distribution of their products. Based on earlier answers, the producers recognize the potential of VAPs, however, for many reasons, they are not currently able to invest into a new and challenging endeavor.

To further quantify interest in VAPs, the producers were asked for their desired payback periods for a $100,000 initial investment into VAPs (Figure F in SI). The purpose of this question was to see if producers would be willing to wait a reasonable amount of time for recouperation of invested funds for value-added products. The most selected years were two, three, and five, requiring a sizeable amount of return in a short period of time. However, when looking back at the ages of these operations, some operations have not even been in business for the above amounts of time, making the venture reasonably seem less achievable, given they likely do not have capital to reinvest yet.

Averages for both the producers' willingness to invest and payback periods relative to their demographics were also investigated (See Table C in the SI). Based on age, all ages, with the exception of 70+ years old, need $2.50/lb in gained value per $1.00/lb invested on average. A similar trend can be seen in regard to payback period with three years being the most common average. Respondents who were 70+ years old declared they were either too old or unwilling to invest more into their

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operation, leading to higher desired gained value for the VAP. Based on gender, women required more gained value ($2.83/lb) when compared to their male counterparts ($2.40/lb) and a similar trend is also observed for payback period. Regarding education, there does not seem to be an obvious trend. Those who have had some college require the most gained value for a VAP ($3.00/lb), while the respondents with a doctorate degree were willing to wait the most amount of time for return on their investment (6 years). These results show that there are some specific demographics (men and those with either an undergraduate or doctorate degree) which are more likely to perceive VAPs as a promising investment to help with their operations' revenue generation, though the small sample size limits any strong conclusions.

Desirable characteristics of VAPs from a producer's perspective were also explored.

Figure 6 explores various advantageous VAP characteristics of which they were asked to choose ones most desirable to them. The two most selected options are related to the economic side of the characteristics, suggesting less of an issue with storing or distribution. This is important because economic gains were the original reasoning for investigating interest in VAPs for aquaculture and aquaponics to aid in stability of the individual business. The figure also shows that investigated products should lean more towards a higher value product rather than one that can be sold to more places or stored for longer, though, ideally, all characteristics would be found in an optimized VAP.

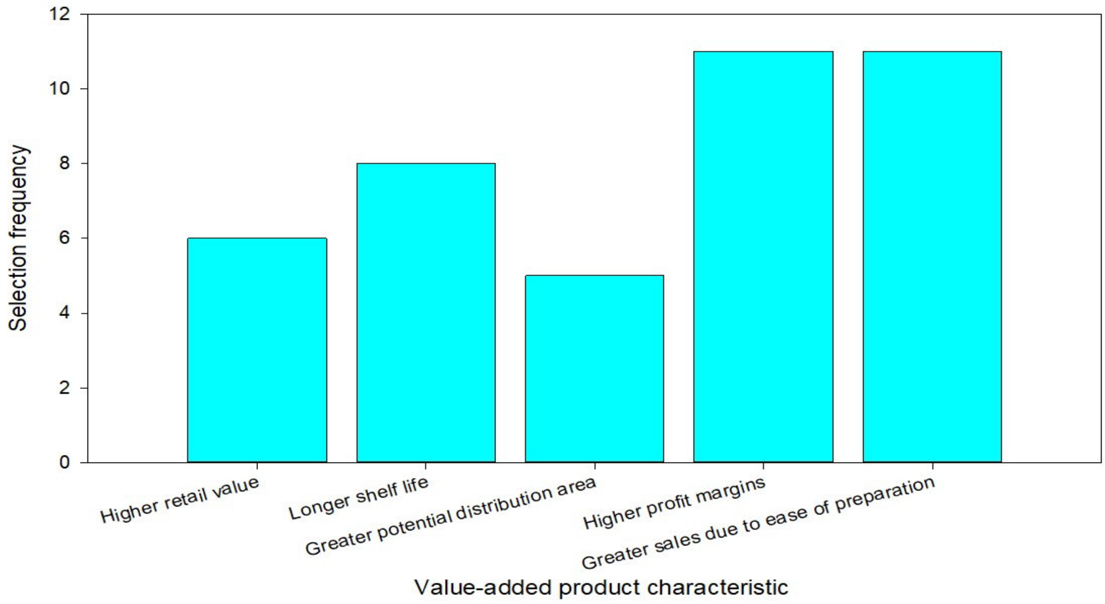

Figure 6. Desired characteristics of VAPs from a producer's perspective.

Willingness-to-pay and payback period were not explored for VRPs as the finances of these products are less straightforward. Quantifying interest in VRPs was not included in the survey as technologies necessary to make these products such as micro-scale anaerobic digestors are still in their infancy, making estimating the cost and value of the products fruitless.

Exploring desirable characteristics is, however, useful so products (with these attributes) could be explored in the future. Disposing of aquaculture byproduct can be a costly endeavor, so VRPs could also help in alleviating disposal costs [17]. Figure 7 lastly explores desirable VRP characteristics, and the survey again asked respondents to choose those most interesting to them. The most selected option was the "displacement of raw materials," suggesting unified interest in reducing waste streams produced in the operations, while also selling new products.

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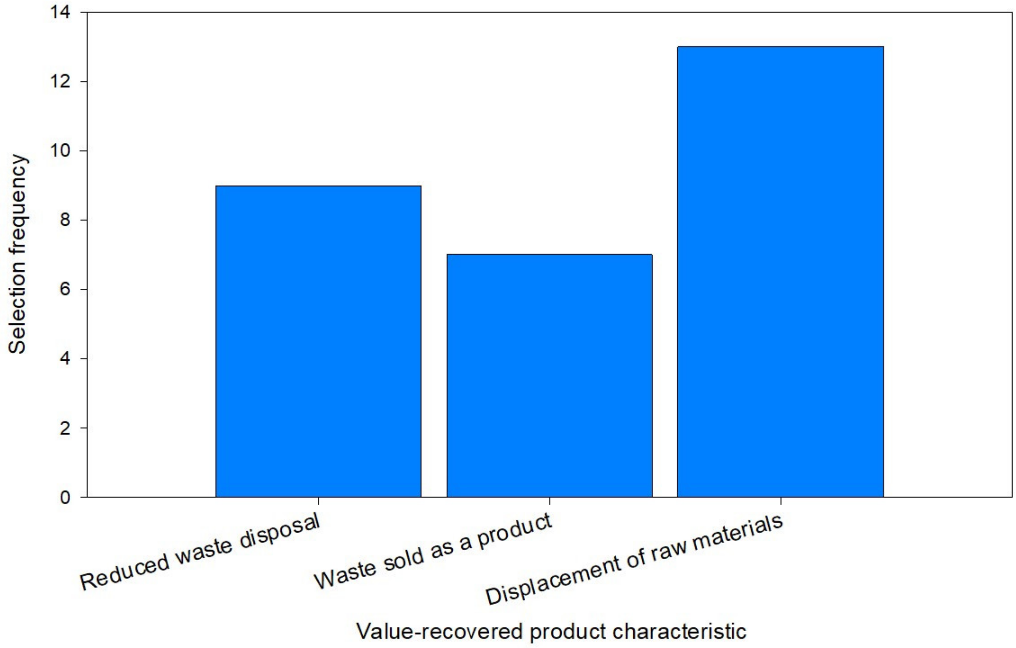

Figure 7. Desired characteristics of VRPs from a producer's perspective.

3.4. Aquaculture & Aquaponics Legislation and Permitting Discussion

One essential and arguably the most perplexing part of almost any agricultural operation in the US is acquiring permits, licenses, certificates along with abiding by all statutes and regulations set forth by federal, state, and local governments, which can cause delays and disruptions in operations that can lead to failure for some. Based on investigation, there is not one single resource to understand all the different rules and regulations around aquacultural and aquaponic activities, leaving tremendous room for error. Figure 8 explores some applicable

Table 1. Example of Federal (USA), State (Wisconsin), and local (Dane county, WI) involved government sectors, statutes, policies, permits, etc.

Government Level	Involved Agencies/Departments	Required Permits, Licenses, and Certifications	Related Statutes and Policies
Local (Dane county, WI, USA)	N/A	1. Zoning permit 2. Stormwater management permit	N/A
State (Wisconsin, USA)	1. Department of Agriculture, Trade, and Consumer Protection (DATCP) 2. Department of Natural Resources (DNR)	1. Building permit 2. General and/or individual water use permits 3. Aquaculture licenses 4. Solid and water waste permits 5. Non-native species permits 6. Food processing plant or retail food	N/A

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		establishment licenses	
Federal (USA)	1. Environmental Protection Agency (EPA) 2. Food and Drug Administration (FDA) 3. United States Department of Agriculture (USDA) 4. United States Army Corps of Engineers (USACE) 5. United States Fish and Wildlife Service (USFWS) 6. Department of Commerce (DOC) 7. Occupational Safety and Health Administration (OSHA) 8. United States Department of Labor (USDOL) 9. National Oceanic and Atmospheric Administration (NOAA)	N/A	1. Marine aquaculture policy 2. Sustainable fisheries act 3. National aquaculture act 4. Magnuson-Stevens fishery conservation and management act 5. National environmental policy act 6. Animal health protection act 7. Commercial fisheries research and development act 8. Clean water act 9. Federal food, drug, and cosmetic act 10. Interjurisdictional fisheries act 11. Lacey act 12. Nonindigenous aquatic nuisance prevention and control act 13. Animal welfare act

statutes and policies, while also displaying the parts of governments involved and the many permits, licenses, and certifications required before even beginning operation. Dane county, Wisconsin was used as the example location because the rules and permitting could be different depending on the state and county. The main governmental stakeholders involved are the USDA, EPA, and FDA as they are concerned with considerations such as the health of the fish, what the operation considers waste streams, how much water is being used, the quality of the food produced, etc. The list of federal legislation is not a complete list; however, these policies and acts are most relevant to aquaculture, which is also the part of aquaponics with the most restrictions in the US.

As discussed previously, surveyed producers recommended increased access to grants, which would aid in the success of aquaculture and aquaponics. Today, many financial aid options exist from both federal and state governments in the form of loans and grants. First, loans and grants from the USDA and NOAA are currently available [18,19]. Lastly, as a part of the 2000 Farm Bill, a value-added grant program was introduced, recognizing the potential in the additions [20]. The grant program aims to ensure businesses' success in their value-added investment, alleviating some financial pressure with initial investments. In 2023, the grant programs made $31 million available for this endeavor [21].

4. Future Work & Recommendations

Since aquaponics is in its relative infancy in the US, there are many routes for future research to go. First, conducting in-person interviews would allow for a more comprehensive understanding of an operation over time and enable more nuance around operational and business challenges and explore avenues such as life cycle assessments of the operation. Second, investigating the "complete" economics (i.e., initial investment, operating costs, profitability, etc.) around operations (with more responses) would allow for a better understanding of the landscape in the US. Lastly, because so little investigation into current markets and trends exists, gaining more high-level information (e.g., relative operation locations, fish types, distribution methods, etc.) from the US relative to the industry is necessary to better understand where successes and potential improvements are.

5. Conclusions

Working to address food security in a sustainable manner is imperative with an evergrowing global population. In the name of sustainability, ensuring economic viability of sustainable food production is equally important. This study focuses on gaining insight into value-added and value-recovered aquaculture and aquaponics products from the perspective of the producers. A survey sent to Midwest aquaculture and aquaponics producers was utilized to fulfill the purpose of the study while also exploring various operational parameters and future directions. The results of the survey found operations of all scales, economic movement, and design. Though many variables were different, challenges such as pests and algae growth were common amongst them. At minimum, most producers recognized the utility in value-added and value-recovered products, while a few seemed genuinely interested in making the investment. Interest in these products by these producers is a dim light, but all new things come with reluctance.

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