Needs Assessment and Practical Solutions for the Aquaponics Industry

by

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Abstract

This research serves as a needs assessment for the aquaponic industry, encapsulating the challenges, knowledge levels, information resource usage, production practices, and production scales of hobbyists, producers, and educators. An online survey was used to collect data from stakeholders including demographics, background, motivations, experiences, challenges, perceptions of core competency areas, usage of informational resources, aquaponic system styles, components, and production practices, fish and plant species produced, system area, volume, production output, and investment. This data was used to evaluate the current state of the aquaponics industry, create guidelines for newcomers, assess needs, and provide recommendations for improving the industry going forward. Major findings from this research are as follows:

Study 1 - Top challenge areas experienced by stakeholders include 1 - operations and management, 2 - facilities, location, and system design, 3 - knowledge and educational resources, 4 - funding, 5 - economic viability, 6 - plant culture, 7 - marketing and distribution, 8 - fish culture, 9 - human factors, and 10 - regulations and certifications.

Study 2 - The top needs for knowledge and information access based on the mean weighted discrepancy score (MWDS) for all groups were in the areas of fish health and disease (FHD) and plant pest, disease, and nutrient deficiencies (PPD), whereas food safety (FS), water chemistry (WC), system maintenance (SM), and system design (SD) needs were higher for some stakeholder groups than others.

Study 3 - The most commonly used information sources overall were internet and videos, books and library, and classes and workshops. The most commonly desired

information resource overall were other aquaponic growers, extension agents, classes/workshops, extension publications, and manufacturers/suppliers. The three most unused resources across all groups were friends and family, consultants, and social media.

Study 4 - Overall, aquaponic systems were largely homemade/do-it-yourself, especially for hobbyists, while producers and educators often used a hybrid of homemade and commercially available technology. Funding sources were primarily personal funds, government grants, and private investor funds. Coupled systems were the most popular overall, which included recirculating aquaculture systems and either deep-water culture or media bed hydroponic units. Plant lighting sources included sunlight, light emitting diode, and fluorescent. Water sources

were typically municipal or wells. Vegetable produce was the most common product sold, followed by training and education, food fish, and microgreens. Tilapia (*Cichlidae*) was the most commonly grown fish species across all groups, followed by ornamental fish (e.g. koi and goldfish; *Cyprinidae*) with 16 other species being reported. The most commonly grown crops overall were lettuce, leafy greens, basil, tomatoes , peppers, and herbs with many additional lesser-grown crops reported. Diversification of fish and plant crops with emphasis on high value and low per unit production cost over time will be critical to profitability going forward.

Study 5 - Fish and plant area, volume, annual production output and investment cost was greatest for producers. System sizes were different by background setting with rural systems generally being larger, more productive, and more expensive than urban systems, and suburban systems falling in between. The relationship between system area and volume, production output and investment were positive and linear when Ln-transformed. Producer systems generally had the greatest variance explained in the regression model, and hobbyists had the least variance. The ratio of plant area to fish area and plant to fish production output were highest for producers, demonstrating that producers tend to focus on plant production. Investment per unit area and volume was highest for producers, while investment per unit production was greatest for hobbyists. Greater industry-combined production area, volume, and invested dollars compared to previous studies suggests the aquaponic industry is growing. Attention to system scale optimization with emphasis on high value and low per unit production cost will be critical to long-term profitability of the industry.

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List of Abbreviations

A	Accessibility
AA	Aquaponics Association
EPA	Environmental Protection Agency
EV	Economic Viability
F	Funding
FC	Fish Culture
FDA	Food and Drug Administration
FHD	Fish Health and Disease
FLSD	Facilities, Location, and System Design
FRK	Financial Record Keeping
FS	Food Safety
HF	Human Factors
I	Importance
K	Knowledge
KER	Knowledge and Educational Resources
MD	Marketing and Distribution
MFP	Marketing Food Products
MWDS	Mean Weighted Discrepancy Score
OM	Operations and Management
PC	Plant Culture
PPD	Plant Pest, Disease, and Nutrient Deficiencies
RC	Regulations and Certifications

SC	System Construction
SD	System Design
SM	System Maintenance
USAS	United States Aquaculture Society
USDA	United States Department of Agriculture
WAS	World Aquaculture Society
WC	Water Chemistry

Chapter 1

Introduction and Literature Review

Background

Agriculture Sustainability and Food Security

Agriculture in the 21st century is burdened with the supreme challenge of feeding, clothing, housing, and employing some 9 billon people globally by 2050 (FAO, 2018), and doing so in a sustainable manner with less resources than ever before. Estimated increases in food demand range from 45-71% from 2010 to 2050 (Keating et al., 2014). The changing climate, increasing population density, decreasing natural resource availability, presence of food deserts, and widening gap in socioeconomic status among various demographic groups are major issues affecting agriculture and the economy (USDA ERS, 2020).

Sustainability in food systems necessitates that present use must not diminish food resources for future generations (Bardach, 2008). The ever-increasing need for resource efficiency requires agricultural solutions that transcend the status quo of production while remaining focused on equity and efficiency. The concept of sustainability is contentious, but one of the most appropriate ways to gauge whether or not a practice or industry is meeting the triple bottom line, which includes social, environmental, and economical elements (Hansmann et al., 2012; Weeks, 2013). If any of these areas are lacking, true sustainability cannot be achieved.

Aquaponics is an agricultural technology that synergizes the production methods and inputs of both aquaculture and horticulture by applying the waste products of fish production to meet the nutrient needs of plants. Palm et al. (2018) put forward the definition that "*aquaponics is a production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms*". Strict aquaponics uses recirculating aquaculture systems and hydroponic plant production, whereas aquaponics farming may include drip irrigation of aquaculture effluent to produce soil crops.

Aquaponics has existed in one form or another for thousands of years (e.g. Aztec Chinampas, Hanging Gardens of Babylon, rice and carp/crayfish polyculture, etc.), however, modern aquaponics researched started in the 1970's and increasingly popularized thereafter (Pillay and Kutty, 2005; Ebel, 2020). Today, social media interest groups around aquaponics have tens of thousands of members, and internet videos about aquaponics have millions of views. People are intrigued by aquaponics because it is both an interesting way of growing, and because it has resource efficiencies that may make aquaponics a sustainable way forward for agriculture.

Goddek et al. (2015) provided a comprehensive review of the challenges to sustainable and commercial aquaponics in a global context, with the top five challenges that the human population face being 1) population rise, 2) climate change, 3) soil degradation, 4) water scarcity, and 5) food security. Aquaponics technology provides opportunities to adapt to these challenges, particularly in arid regions or those without arable land (Goddek et al., 2015). Growing populations require increased animal protein production, with fish being one of the healthiest and feed-efficient options (Fry et al., 2018). From an environmental and practical application perspective challenges to aquaponic sustainability include optimizing the production environment (e.g. water chemistry, pH, biological filtration, temperature, and light), maximizing production outputs (e.g. fish and plants), and minimizing effluent discharge into the environment (Tyson et al., 2011). Efficiency in mineral cycling (e.g. nitrogen, phosphorus and potassium fertilizers), enhanced water and energy consumption, reduction of overfishing, and promoting shorter supply chains through local production are global social and ecological challenges that aquaponics can address (Goddek et al. 2015).

The applicability of aquaponics for meeting the needs of many are also related to its ability to adapt to local conditions. König et al. (2016) reviewed aquaponic sustainability with relation to the food-water-energy-nexus finding that the sustainability of aquaponics is very difficult to assess because of the variety of systems and interconnectedness of markets, value chains, communities, available infrastructure, and policy. Three main scenarios used to evaluate these adaptations included 1) urban agriculture, 2) developing countries, and 3) industrial-scale. Urban aquaponics could be used to address food deserts, for its healing effects in rehabilitation centers, and for connecting people with nature. Developing countries can use aquaponics to grow reliable, high-quality protein to facilitate food safety and food sovereignty, although challenges include the cost-prohibitive expense of infrastructure, dependency on high quality water, reliable electricity, and energy. Industrial aquaponics requires up-scaled facilities for economic viability, as is businesses are generally only profitable at scales greater than 1,000 m^2 (König et al., 2016). Risk of failure with industrial facilities is high, with catastrophic outcomes for producers and investors.

Aquaponic Applications

Aquaponics is a tool to promote and wellbeing, remote and off-grid food production, local environmental benefits like waste reduction and heavy metal sequestration, decreased energy consumption through careful system design, decreased greenhouse gas emissions (Greenfeld et al., 2019). Aquaponic stakeholders use this technology for a variety of reasons, including pleasure, healthy food, environmental sustainability, education, making money and international development (Love et al., 2014).

The interest in aquaponics from an education perspective relates to the recognized needs for improved public health and the importance of spending time in the natural environment (Genello et al., 2015; Williams and Dixon, 2013). Learning benefits include 1) increased academic performance, 2) increased diet preference for healthy food, 3) personal development, cooperation, and 4) environmental awareness (Genello et al., 2015; Parmer et al., 2009; Morgan et al., 2009; Williams and Dixon, 2013). Learning outcomes for STEM education using aquaponics can be applied in a variety of academic disciplines, especially agriculture, biology, engineering, nutrition, chemistry, and technology (Genello et al., 2015). Aquaponics provides the opportunity for experiential, collaborative, and project-based learning (Wardlow et al, 2002; Genello et al., 2015) as well as systems thinking (Junge et al., 2014).

Aquaponic Benefits

Some advantages that aquaponics has over traditional agriculture include popularity, marketability, resource efficiency, enhanced production rates, superior product quality, scalability and adaptability (Pattillo, 2017a; Pattillo, 2017b). Take water, for instance. In a coupled, or fully recirculating, aquaponic system, the plants act as filters for the nutrients in the water generated during the feeding process. Thus, the plants get the nutrients they need, and the fish get cleaner water. This helps reduce the waste discharge rates into the environment, thereby reducing the environmental footprint. Additionally, plants tend to grow at an accelerated rate in aquaponic systems when compared to field-grown crops (Resh, 2013; Pattillo, 2017a). This is mostly due to water availability and the nutrients being dissolved in a proper form for the plants to adsorb. Other plant growth enhancements include reduced soil-borne diseases allowing plants to grow at their optimal rate. Similarly, production space requirements are reduced, and crop rotations are accelerated. These enhancements to field production, when coupled with controlled environments agriculture (e.g. greenhouse production) allow for year-round production under ideal growing conditions, which could prove to be a major advantage of aquaponics (Pickens et al., 2016; Pickens and Danaher 2016).

Additionally, fish production in recirculating aquaculture systems is water efficient, with reuse rates around 95% to 99% (Dalsgaard et al., 2013; Timmons and Ebeling, 2013), and using as little as 100 L of water used per kilogram of fish produced (Martins et al., 2010), compared to 5,000 to 20,000 L per kg of beef (IME, 2013). Feed conversion ratios (FCR) tend to range between 1 to 3 kg of feed required to produce 1 kg of fish, which is more efficient than pork and beef (Fry et al., 2018). Regular feeding of fish generates waste nutrients in the effluent stream, but when recirculating aquaculture is combined with hydroponic plant production, the waste stream is sufficient in nutrients to produce two to nine kg of crops for each kg of fish feed applied, in addition the 0.5 to 1 kg of fish (Love et al. 2015a & 2015b). Daily fish feed requirements to maintain a square meter of healthy crops in aquaponics ranges from 15g to 100g depending on crops, feed and nutrient inputs, production method, and environmental conditions (Rakocy, 2004; Endut et al., 2011; Goddek et al, 2015; Petrea et al., 2016).

Aquaponics can be used to teach STEM subjects (e.g. chemistry, physics, biology, and sustainability), provide benefits of hands-on, experiential, and integrated learning, and establish connections between food, agriculture, and global trends (Hart et al., 2014; Schneller et al., 2015). Additionally, aquaponics can be used to teach systems thinking processes (Junge et al., 2014). Schneller et al. (2015) praised aquaponics for its adaptation to school schedule and location constraints, in colder environments and particularly in urban environments where land may not be available for a greenhouse. Additionally, teachers and parents noted an increase in academic performance for students with learning disabilities like attention deficit hyperactive disorder (ADHD). Clayborn et al. (2017) found that using a small-scale aquaponic system affected test scores and attitudes toward sustainability and aquaponics. Attitude improvements included a) desire to become more sustainable, b) willingness to recommend aquaponics to others, c) desire to pursue aquaponics personally, d) observed interest from others in aquaponics after exposure to their system, e) perceived usefulness of aquaponics to teach math and science, f) decreased perception of aquaponics workload requirements (Clayborn et al., 2017).

Industry Overview

The aquaponics industry has a variety of stakeholder groups including hobbyists/home gardeners, educators, producers (for profit and non-profit), consultants, manufacturers, suppliers, retail merchants, researchers, regulators, processors, transporters, and more.

These groups all have a vested interest in the success of aquaponics but contribute in different ways. Aquaponics is practiced globally, but much of the activity is in the United States, Canada, Europe, and Australia (Love et al., 2014).

Aquaponics is still a young industry, with issues that have prevented it from becoming a staple of food production, most importantly investment cost and ongoing production cost. Because aquaponics is simply an alternate production method for crops that already exist in the marketplace, price competition is a serious stumbling block. The ability to produce cheaply is critical to success, and aquaponics is notoriously expensive relative to traditional field-grown crops. Competition from a worldwide market that is not subject to the same stringent environmental regulation constraints, as well as access to cheap labor in developing countries, has made aquaponic products economically undesirable to the general public (Engle, 2015). Producing at an appropriate scale is integral to achieving production price points that align with what the general is willing to pay.

According to Love et al. (2015a), 31% of commercial producers claimed to be profitable, while others (55%) predicted profit in next 12 months, and 75% predicted profit within 36 months. Profitability of operations generally started at $50,000 in gross income per year. Forty seven percent of aquaponic farmers also conducted other farming enterprises, with fish and produce sales most commonly occurring on-farm. Other markets for fish included restaurants, other producers (e.g. stockers and fingerlings), and farmer’s markets. Plants were commonly sold at the farmers market and restaurants, followed by grocery stores. Smaller (not profitable) farms tended to focus on local food sales in limited niche markets, which was their only option considering production scale.

Investment amount and profitability were not significantly correlated, however factors that did significantly correlate with profitability were: 1) Aquaponics as their primary source of income (Odds ratio (OR) = 5.79), which suggests personal vesting in system success. 2) Location in USDA Plant Hardiness zone between 7-13 (OR = 4.17), implying that warmer climates were more likely to profit due to reduced heating cost and longer growing seasons. 3) Gross sales revenue > $5,000/yr (OR = 3.58), meaning that producers sold more products, which made them more profitable. Skill and effort in marketing likely was the main driver, however better produce quality and product shelf life, as well as higher sales prices likely contributed. 4) Greater aquaponics knowledge (OR = 2.37), suggesting that being more knowledgeable about system functions and maintenance decreased risk of catastrophic failure, making them more profitable. 5) Sales of non-food products (e.g. materials, supplies, consulting services, workshops, and agritourism) (OR = 2.13), implying that sales of fish and plants alone are not enough to be profitable. Improved sales price, consumer knowledge and acceptance of aquaponic products will be critical to enterprise profit in the future (Xie and Rosentrater, 2015; Quagrainie et al., 2017; Baganz et al., 2020; Greenfeld et al., 2019; Short et al., 2017; Abbey, 2018).

System Design Strategies

A variety of aquaponic system models have been developed to make use of nutrient-rich aquaculture effluent (Diver, 2006). There are two main nutrient flow strategies for aquaponic production - coupled and decoupled. A coupled aquaponics system fully recirculates the water between the aquaculture and hydroponic subsystems. The system developed at the University of the Virgin Islands (UVI) is a good example of a coupled system (Rakocy et al., 2004). In general, the system includes a fish culture unit, solids filtration, biological filtration, aeration, hydroponic unit, and a sump with a pump. Additional system components include a mineralization tank, nutrient addition, pH modification, and some form of water sterilization. The benefits of a coupled system are water, energy, and nutrient use efficiency. Because the water is recirculated, the plants are able to take full advantage of the nutrients, scrubbing the water to improve water quality for the fish. Also, the energy that is used to heat or cool the water in the system is used more effectively, since the water remains in the system until it is transpired by the plants, evaporated, or discharged as sludge.

Drawbacks to coupled systems stem from the interconnectedness of the system. Aquaponic system optimization between fish and plant needs for water quality (e.g. pH and nutrient balance), temperature, and pest and disease management can be challenging, therefore matching species tolerances is critical for coupled systems (Goddek et al, 2015). For example, the pH of the water is optimal for fish, plants, and beneficial bacteria at different ranges, which forces a compromise leading to lost productivity. This compromise is also the case with temperature. Therapeutants and pesticides that could normally be used in the fish or plant culture components may bring harm to their respective counterparts, therefore pest and disease management options are limited. A balance between fish species needs and plant species needs is critical in coupled aquaponics systems, which may not provide the best business outcome for producers.

Decoupled systems, like the one developed at Auburn University (AU), were developed to address the shortcomings of coupled systems. The aquaculture and hydroponic components are separated, or decoupled, to allow for independent management of system parameters to optimize production (Monsees et al., 2017). Decoupled systems do not return water to the aquaculture unit once it has passed through the horticulture unit; as such, the aquaculture unit functions independently as a recirculating aquaculture system (RAS) and the waste discharge is collected for irrigation water in the hydroponic unit. Strategies for decoupling include multi-loop recirculating systems (e.g. double recirculating aquaponic systems or DRAPS) (Kloas, 2015; Goddek and Körner, 2019; Suhl et al., 2018) and single pass or drain-to-waste irrigation systems (Blanchard et al., 2020; Pattillo et al., 2020; Pickens et al., 2020). The advantages of decoupling include improved control over water quality, nutrient concentration, nutrient availability for plant uptake (e.g. pH), a greater breadth of horticulture technique options, and greater latitude for pest management with pesticides. Aquaponics in the DRAPS configureation can reduce hydroponic fertilizer requirements by 23.6% for tomatoes, equating to an additional 10.3 kg of tomato produce per kg of hydroponic fertilizer added (Shul et al., 2016). With nitrogen loss reduction enhancements, the DRAPS system allows more efficient production of tomato using *Clarias* catfish, reducing fertilizer inputs by 13 to 78% compared to the hydroponic control (Suhl et al., 2018).

Commercial Practices

The most common fish species raised is tilapia, with ornamental fish being commonly raised by those who also sell non-food products like education, supplies, and consulting services (Love et al., 2014). Typical hydroponic units include deep water culture (DWC or floating rafts), media beds (flood and drain or continuous flow), nutrient film technique (NFT), and drip irrigation (Dutch or Bato buckets and field crops), with growing interest in vertical towers, wicking beds, and aeroponics (Love et al., 2014; Goddek et al, 2015; Pickens et al., 2016; Pattillo 2017a). Common crops include leafy greens, herbs, tomato, pepper, and cucumber, which are commonly grown in DWC, media beds, and NFT, with a combination of natural and artificial light, mostly in greenhouses (Love et al., 2014). Production levels in aquaponics compared to conventional hydroponic varies, however, when nutrient supplementation is used to correct deficiencies, aquaponics tends to outperform hydroponics (Ayipio et al., 2019). To take full advantage of nutrients available in fish feeds, the waste products must be broken down to their elemental forms through mineralization, which can include aerobic and anaerobic digestion as well as composting worms (Goddek et al., 2015).

Production Efficiency

Love et al. (2014) reported 9 kg of produce could be generated from every 1 kg of feed input into the system (9:1). In a later life cycle assessment of aquaponics, Love et al. (2015b) estimated a FCR of 1.29 for tilapia, and a maximum plant to feed ratio of 5:1 for leafy greens during the spring growing season. On average, 1 kg of crops required 104 L of water, 0.5 kg of feed, and 56 kWh of energy, making the plant to feed ratio closer to 2:1.

The major constraint of growing in a temperate environment is the cost of providing heat for the fish and crops. The average monthly energy cost to produce 1 kg of plants was $6 but ranged from $1/kg from May to August to as high as $55/kg in January (Love et al., 2015b). Tokunga et al. (2015) reported an energy cost of $0.73/kg for lettuce in Hawaii, where heating is not an issue.

Goddek and Kröer (2019) modeled aquaponic production outcomes for multi-loop aquaponic systems with tomatoes in cold, temperate, and tropical production environments, finding that system optimization is site specific, with plant and fish production rates being greatly affected by the production environment. Locations with more stable environments and low seasonal variation in temperature were more efficient with relation to energy consumption and nitrate uptake by plants. Additionally, the distillation of water from the air to use in the system was predicted to improve RAS efficiency to a very high degree. The most important factors for economic success were 1) economies of scale, 2) chosen crop and sales opportunities, 3) market prices, 4) energy prices and availability, and 5) labor cost (Goddek and Kröer, 2019), which agrees with Love et al. (2015a), who found that facilities located in warmer climates (e.g. plant hardiness zones 7 thru 13) were 4.17 times more likely to be profitable.

A critical consideration for producers is the sales price for produce, particularly relative to production cost. It may be prudent to shut the system down for parts of the year to save on production costs. Winter production can be cost-prohibited when heating and lighting requirements exceed the sales price. Competition from local field crops is lower during cold weather, which could be advantageous to aquaponic farmers growing in a greenhouse given a high enough sales price, however imported produce is still a major competitor. A focus on quality, taste, and freshness is necessary to stay competitive (Junge et al., 2017). It is important to consider financial losses during cold weather relative to the monthly cash flow and overall profitability to determine whether sustaining those losses is worth maintaining that clientele.

System Scale

Aquaponic technology can be applied at many scales including commercial or industrial-scale facilities at the large end, community-based or urban agriculture in the middle, down to backyard, classroom and benchtop systems at the small end. Proper scaling of aquaponic facilities is critical to resource use efficiency and economic success. Net zero discharge facilities with high electricity, water, and energy demands require intensive management, thus the sustainability designation for aquaponics necessitates thorough life cycle assessment. Xie and Rosentrater (2015) performed a Life Cycle Assessment (LCA) and technoeconomic analysis (TEA) on tilapia and basil aquaponics in the Midwestern USA based on a prototype system with a scale-up factor for production at 10x and 300x. System scale and basil sales price were critical factors determining profitability, with economies of scale observed at larger scales (> 75 m^2 growing area) and greater profit potential at higher sales prices promoting profit (>$60/kg for basil) (Xie and Rosentrater, 2015). Quagrainie et al. (2017) found that investment cost and annual operating cost also increased with farm size from $65,000 and $127,074 (small), to $125,000 and $181,741 (medium) to $250,000 and $360,350 (large), respectively, with greater profit potentials observed in larger farms. Maucieri et al. (2018) provided some system scale designations ranging from micro (<5 m^2), very small (5-50 m^2), small (50-200 m^2), medium (200-1,000 m^2), to large (>1,000 m^2). König et al. (2016) suggests that commercial businesses must be at least 1,000 m^2 in size to profit. Because the expense of research and teaching systems at large scales can be cost prohibitive for schools, Maucieri et al. (2018) performed an LCA on micro-scale aquaponics for educational purposes, concluding that small-scale systems provide data that can be reliably extrapolated to model larger systems. An additional benefit of teaching with small-scale aquaponic systems is that their environmental impact is relatively low compared to education alternatives like textbooks and e-books (Maucieri et al., 2018).

Controlled Environments Agriculture

Controlled environments agriculture (CEA) uses built structures (e.g. greenhouses, high tunnels, shade houses, and warehouses) to influence the growing environment with respect to temperature, humidity, light intensity, and duration to improve crop performance and extend the growing season. Controlled environments also shield the crop from harmful weather conditions and pests, reducing crop damage, optimizing growth conditions, and maximizing plant quality and production. However, construction and operating costs for a greenhouse can be quite high; therefore, it is imperative that plant production is optimized to ensure that the cost of the CEA facility is worth the investment. In an LCA of cold weather aquaponics, Ghamkhar et al. (2020) found that the majority of environmental impacts (>88%) came from heating, electricity, equipment, and fish feed, recommending improved efficiency of space heating, improving equipment lifespan, and using fishmeal-free diets to reduce the environmental footprint.

A cold weather adaptation for aquaponics is indoor or warehouse farming in well insulated buildings where the growing environment can be easily regulated (Eaves and Eaves, 2018). These ‘plant factory’ operations can produce more plant biomass per unit area than greenhouses and are highly water efficient, consuming only 2% of a similar size field operation, by condensing and reusing water that has evapotranspirated from the crops (Avgoustaki and Xydis, 2020). To maximize space and heating efficiency, many of these farms have focused on vertical production in shallow trays on racks with 3 to 5 layers or more with grow lights directly above the crops (Avgoustaki and Xydis, 2020; Eaves and Eaves, 2018). Indoor operations are completely dependent on artificial light for growing crops and the electrical usage per kg of crop produced can be seven times as much as in a greenhouse (Avgoustaki and Xydis, 2020). Cost savings from reduced heating requirements can, under optimal conditions, offset the electrical cost of lighting and even outperform greenhouse production profitability (Avgoustaki and Xydis, 2020; Eaves and Eaves, 2018). Plant factories can be located in urban areas with access to waste heat from power plants and take advantage of 'off-peak' power (e.g. night time, low-cost electricity), in order to maximize profit (Avgoustaki and Xydis, 2020).

Minimal research into indoor aquaponic production has been conducted, however businesses like this have operated over the past several years, some of which have failed (Graber et al, 2014). A study of consumer acceptance of aquaponically grown basil revealed that cultivar and growing method significantly impact consumer acceptance, with basil varieties grown under warehouse conditions being less desirable than those grown in greenhouses (Yue et al., 2020). Under the same environmental conditions, lettuce varieties were grown in combination with Koi, resulting in smaller lettuce fresh and dry weight in the warehouse environment (Abbey et al., 2020). This was the same trend for warehouse-grown strawberries, which had lower fruit count per plant, and individual fruit wet and dry weight compared to their greenhouse-grown counterparts (Abbey et al., 2019). Sustainability of plant factories will require responses to these issues, and likely necessitate operating in an urban environment where consumers are able to pay more for the product (Avgoustaki and Xydis, 2020).

Aquaponic Challenges and Barriers to Adoption

Economic Challenges

Aquaponics has the appearance of being environmentally sustainable because of its water, nutrient, and space use efficiency. Because of this positive environmental image as well as its use of interesting growing technology, aquaponics has captured the imagination of people around the world, giving it a high degree of social sustainability. However, from an economic perspective aquaponics falls short (Weeks, 2013; Greenfeld et al., 2019). The high infrastructure cost, production costs, especially in controlled environments, and complexity of system design and maintenance requires skilled labor make aquaponics unsustainable economically.

König et al. (2018) analyzed aquaponics as an emerging technological innovation system, cautioning newcomers that aquaponics is in the high-risk formation stage for entrepreneurs and investors, which can last for many years. The formation period is characterized by lack of meaningful prices or clear demand, which makes business planning difficult. Claims regarding sustainability should be tempered to clearly illuminate the true sustainable aspects of aquaponics to avoid losing legitimacy. The way forward for aquaponics is unclear and viewed differently by various stakeholder groups (König et al., 2018). Greenfeld et al. (2019) described the major economic barriers to aquaponic commercialization to as a) low consumer interest and awareness of aquaponic products, b) the external benefits of aquaponics (e.g. minimal effluent discharge, etc.) are not realized by the farmer and thus don't provide direct incentive, c) it is unclear which aquaponic adopters will become successful.

However, there is still hope for economic sustainability. Fern (2013) described construction costs for a low-tech, tilapia-cucumber aquaponic facility in Alabama with a breakeven total cost of tilapia at $1.16/lb and $0.25/lb to produce cucumbers, providing ample margin for profit at retail prices. With high infrastructure costs it is critical to select crops that maximize returns based on market value, production rate, and production area required, which is typically done with leafy greens (e.g. lettuce) and herbs (e.g. basil) (Bailey and Ferrarezi, 2017). Quagrainie et al. (2017) analyzed the enterprise budgets of aquaponic farms operating at three different scales in the Midwestern US. Sensitivity analysis indicated that all three farms were able to profit when basil price at least $10.00/kg, although the net present value (NPV) grew as farm size increased from small ($696), to medium ($9,385), and large ($41,827) (Quagrainie et al., 2017).

Baganz et al. (2020) evaluated the economic potential of a decoupled, multi-loop aquaponics production system at various scales for the production of *Clarias* catfish and tomatoes under greenhouse conditions with supplemental income from surplus electricity sales from a gas-based combined heat and power unit in Germany. The optimized scenario maximized fish production and plant production in an urban or suburban environment on 2,000 m^2 (0.5 acres) such that 2.1 kg of tomatoes were produced per 1 kg of fish. This is similar to the average plant yield to feed input ratio described by Love et al. (2015b). Heat energy is required for warm water species like *Clarias* catfish and tilapia, while electricity is required for running other components of the system, thus the combined heat and power unit was a feasible alternative to grid electricity in this scenario, generating approximately $14,642 in additional revenue annually. This option increased profit potential, especially for smaller size farms. Economic outcomes from the system optimization brought the profit level from a loss, up to a gain of $0.37/kg fish and $1.52/kg of tomato. The total investment for this project was $930,440 including land ($35,330), production facilities ($730,220), and the first year of operating expenses ($164,890), with a payback period of 11.8 years on a 15-yr loan, or 8 years without loans.

For farmers to succeed, they must focus on key economic considerations like 1) overall investment for facility and equipment, 2) annual operating cost, 3) realistic estimates of market prices for products, 4) the degree of competition within the market, and 5) realistic projections of revenue (Engle, 2015).

Consumer Perceptions and Education Needs

Consumer perceptions of aquaponics have been studied in the U.S. (Short et al., 2017;), Australia and Israel (Greenfeld et al., 2020a), Romania (Zugravu et al., 2016), and other parts of Europe (Miličić et al., 2017), revealing a general lack of awareness, with only 33% to 50% of the population being familiar with aquaponics (Short et al., 2017; Miličić et al., 2017). Because of this lack of recognition, consumer willingness to pay for aquaponic products is typically similar to conventionally grown crops (Abbey, 2018), especially for those who cannot distinguish between them. Market segmentation for aquaponic consumers varies by location, culture, gender, values, income, local food options and preferences, and environmental constraints (Junge et al., 2017; Miličić et al., 2017; Greenfeld et al., 2020a).

Consumer preferences generally are affected by attributes of product, such as healthfulness, environmental friendliness, sustainability, taste, freshness, and quality (Short et al., 2017; Junge et al., 2017). Product qualities that align with sustainable consumption include 1) items must be non-polluting, 2) the consumption process does not pollute the environment, and 3) environmental destruction is actively avoided by conserving goods and resources, thus preventing waste (Connolly and Prothero, 2008; Xu et al., 2018). Individuals that are willing to pay more for aquaponic produce are educated, command a higher income, and are more commonly female and are generally environmentally minded, commonly consuming “organic” food products (Abbey, 2018; Greenfeld et al., 2020a). Premium prices could be obtained for aquaponic produced when potential customers were educated about attributes like “pesticide free”, “organic”, “all natural”, “non-GMP”, etc. (Zugravu et al., 2016; Short et al., 2017; Miličić et al., 2017; Abbey, 2018).

It should be noted that various markets react differently to aquaponic produce regarding willingness to pay and willingness to consume, therefore production strategies, particularly operational scale should be catered to local market dynamics. For example, Australians were not willing to pay a high premium, but a larger portion of the population was willing to consume aquaponic produce, thus profit could be maximized at larger scales that generate larger volumes of product (Greenfeld et al. 2020a). Alternatively, in Israel, a small segment of the population was willing to consume aquaponic produce, but they were also willing to pay up to twice as much as conventional price, thus a smaller operation with lower production volumes could maximize profit (Greenfeld et al., 2020a).

Greenfeld et al. (2020a) recommended consumer education as a primary means of enhancing sales prices and generating more profit for the farmer. Education should be pursued at the retail store level and news sources because consumers tend to display trust and preference in these outlets (Zugravu et al., 2016; Short et al., 2017). A major consideration, however, is that higher end markets tend to have higher documentation standards for product quality and food safety practices (Engle, 2015), which may increase production cost.

Financing Challenges

Due to high infrastructure cost, access to capital is a major barrier to entry for commercial aquaponics, which is exacerbated by the fact that bank loans are virtually inaccessible to farmers (Villarroel et al., 2016; Turnsek et al., 2020). Lack of financing options is due general unfamiliarity with aquaponics as well as few documented examples of profitable business and business plans. As reported by Love et al. (2015a) and Villorreal et al. (2017), producers have little choice but to use their own personal funds or find private investors. Colleges and K-12 schools typically fund their operations with a combination of government grants, donor funds, and sale of produce or educational resources (Genello et al., 2015).

Loan opportunities must be granted for the industry to grow and may only be done when the perceived risk to loan agencies is low (König et al., 2018). Government-backed loans may be an opportunity to reduce this risk and allow farmers to get the financing they need (Greenfeld et al., 2020a; Brewer, 2019). Once successful aquaponic operations are established, the perceived risk will be lower and conventional agricultural loans will become more readily available.

Location Challenges

Aquaponics can be practiced under virtually any background setting making it an excellent tool to fight against food deserts by producing food in unused urban infrastructure like warehouses. Controlled environments, such as greenhouses or warehouses, allow a farmer to completely alter the ambient growing environment with regard to temperature, relative humidity, light intensity, and air flow. Because aquaponics does not require soil, the local topography, geology, and climate are relatively unimportant to the ability to run a successful aquaponics production facility. However, these factors do play into profitability, especially infrastructure and input costs. It is entirely possible to use aquaponics to grow crops in Antarctica, however, the cost of heating and lighting would likely make commercial production under those conditions cost prohibitive. Most of the early research into aquaponics was done at the University of the Virgin Islands and the University of Hawaii. Both of these tropical locations provide ideal temperature and light conditions for crop production year-round, even without the use of a greenhouse (Rakocy et al., 2004).

Additionally, there are zoning restrictions (e.g. non-agricultural zoning – excludes livestock) that must be dealt with on a local level. Because most newcomers to aquaponics may be first time business owners, local zoning ordinances may be confusing and outdated. Zoning laws are in place to plan land usage to benefit the local home and business owners and provide a safe and clean environment. Urban agriculture is a relatively new concept that may not have legal precedence under local zoning laws, especially for aquaponics. Many municipalities still need to expand or loosen their definition of urban agriculture to include aquaponics, particularly within a warehouse/industrial setting where mixed uses may include agriculture, tourism, and on-farm sales (Tomlinson, 2015).

In developing countries, aquaponics meets a different set of challenges. Brewer (2019) evaluated barriers and incentives to engaging in aquaponic production in Brazil, finding that local farmers were generally unknowledgeable about aquaponics, but interested in learning more about it. Once educated, 47% of farmers did not view aquaponic system complexity as a barrier, and 38% would try aquaponics if there was a guaranteed market. Time, money, production cost, markets, workforce, water access, land, road infrastructure, and knowledge were cited as the main barriers to aquaponic adoption. If a greater workforce was available, farmers would be more likely to expand farming operations. A strong desire for cooperative systems for sharing knowledge and resources was described by the farmers. Access to inputs for constructing and operating a successful aquaponic system was cited as the top concern for aquaponic practitioners in Brazil (Silva et al., 2019). Brewer (2019) recommended government intervention to support aquaponic adoption through provision of aquaponic system kits, reduced bureaucratic hurdles, guaranteed purchase contracts, and training for farmers.

Operational Challenges

Labor is a major bottleneck to profitability in aquaponics, making up nearly half of the annual operating cost (Engle, 2015; Tokunaga et al., 2015). According to Quagrainie et al. (2017), labor requirements for various farm sizes ranged from 23 hr/day (small), 31.2 hr/day (medium), and 65.8 hr/day (large). Many operations use a combination of full time, part time, and volunteer labor, which varies depending on facility goals (e.g. making money vs. community engagement (Love et al., 2015a).

Aquaponics does, however, provides enhancements that eliminate some of the more labor-intensive aspects of agriculture, namely weeding, planting, and harvesting. Hydroponic growing methods use sterile substrates, free of weed seeds, which can be grown at any desired height to facilitate worker productivity and reduce strain. These improvements can vastly reduce labor needs over the course of a production cycle, making aquaponics more competitive. Technology, specifically automation of seeding and harvesting, can greatly reduce labor needs as well as food safety concerns. Machines can perform tasks repetitively in a fraction of the time it takes for a laborer, and often with less variation and fewer mistakes. This leads to consistency of product, reliability of results, and fewer human resource issues overall. Finding labor with the proper skills that show up to work consistently and will work for relatively low wages is very difficult. Increasing workforce development efforts at the high school or community college level would be advantageous to improving the skilled labor pool for the aquaponics industry.

Education Challenges

Although aquaponics is an effective tool to teach systems thinking, proper monitoring procedures, planning and implementation, independent and group working skills, and environmental literacy, there are some challenges for implementation by educators. Schneller et al. (2015) described barriers to adoption for teachers including time, resources, administrative support, and constraints imposed by strict teaching standards. Furthermore, Hart (2013 & 2014) described top challenges for educators were 1) technical difficulties encountered while planning, building, and running the system, 2) space, infrastructure, and administrative support restrictions associated with operating in a school setting, and 3) finding time and labor to run and maintain the system, especially through summer break and holidays. Junge et al. (2014) reported constraints of teaching with aquaponics to include budget restrictions, lack of time, and excessive effort requirements.

Knowledge Challenges

Knowledge is a commonly identified barrier to successful aquaponic adoption (Love et al., 2014). Inherent risks to aquaponic newcomers include navigating the tribulations of successfully financing, permitting, and constructing a well-functioning system, learning how to operate that system to produce marketable crops that comply with food safety and certification standards, and finally marketing the product at a price that promotes profitability. Major risks in the first year of an aquaponic business include a steep learning curve, high fish mortality, nutrient deficiencies, incompatible plant cultivars for aquaponics, root rot, system malfunction and flooding (Savidov, 2004).

Love et al. (2014) assessed knowledge level by asking participants to respond to a series of seven competency areas related to effectively running an aquaponic system. Respondents felt very confident about water chemistry and plumbing, fairly confident about fish and plant husbandry, and marginally confident that they knew regulations regarding fish sales. To assess the effect of experience on grower knowledge, Greenfeld et al. (2020b) analyzed knowledge levels of recent aquaponic adopters. Over half (59%) of respondents had some prior aquaponic knowledge, however 41% did not have sufficient fish or plant knowledge during their first year of operations. Participants with up to two years of aquaponic experience reported higher knowledge levels than those with one year or less, implying that some skills can be learned through trial and error.

Even from the home and garden store perspective, who supply many of the construction and plumbing components of an aquaponic system, the employees were not comfortable answering question about structural components, nutrient cycling, or fish and plants (Campbell et al., 2015). Big box store employees and management had more familiarity with aquaponics than small ‘mom and pop’ garden stores (Campbell et al., 2015). Because of the frequency with which aquaponic practitioners of all groups tend to use box stores to obtain equipment and supplies, Campbell et al. (2015) recommended a formal training on aquaponics to be delivered to store employees and management.

Information Challenges

Obtaining reliable information can be challenging for aquaponic newcomers, particularly due to the overwhelming amount of unvalidated information available on the internet (Junge et al., 2017. Following Junge et al. (2017), the hype ratio [hype ratio = google search results / google scholar search results] for “aquaponics” in February 2020 was 1,400:1, which is considerably higher than “hydroponics” (637:1), “agriculture” (300:1), “sustainable agriculture” (185:1), horticulture (31:1), and aquaculture (13:1) (Table 1). As the rate of publishing scientific research on these topics increases, the hype ratio falls by increasing the denominator. Although this method is biased toward internet searchable literature, it is an informative index of the general public’s interest compared to scientific understanding. This can be interpreted, also, as the potential for newcomers to aquaponics to encounter misinformation on the internet that could potentially lead to failure.

Common information sources used by educators include (in descending frequency) internet websites, other growers, print resources, university or extension, and seminars or workshops, with state and federal agencies used least frequently (Genello et al., 2015). It is critical for beginners to have access to good quality information to facilitate their success. Greenfeld et al. (2020b) recommended providing more training and mentorship opportunities through university teaching and extension, K-12 education, and professional associations for incoming producers to manage risk to new operations.

Regulatory Challenges

Regulatory issues associated with aquaponics are broad, with multiple agencies regulating water quality, interstate transport of fish, food safety and processing, business, land use and zoning at the local, state, and federal level (Engle and Stone, 2013). Not only do farmers need to be able to run the system, which is complicated in itself, they also have to operate in an environment of increasing scrutiny of agriculture practices and products (Engle and Stone, 2013; Goddek et al., 2015). Consumers often judge the quality of produce by certification labels such as being 'organically' grown; however, compliance with certification standards like GAP or organic can be challenging and certification standards tend to change (Kledal et al., 2019). Love et al. (2014) found aquaponic practitioners felt only marginally confident that they knew regulations regarding fish sales. Love et al. (2014) recommended diversifying the fish species beyond tilapia as they are an exotic species that could present regulatory hurdles in the U.S. Live ornamental fish sales allow growers to bypass food safety and processing regulations, but interstate transport laws may apply (Engle and Stone, 2013). Permitting requirements for aquaculture effluent discharge also apply to aquaponic facilities producing more than 20,000 lbs/yr for coldwater fish (e.g. trout) and 100,000 lbs/yr for warmwater fish (e.g. tilapia) (US EPA, 2020). Fortunately, due to the water and nutrient-efficient nature of aquaponics, an exemption under this rule is obtainable for smaller and well-designed facilities.

Additionally, there are zoning restrictions (e.g. non-agricultural zoning – excludes livestock) that must be dealt with on a local level. Because most newcomers to aquaponics may be first time business owners, local zoning ordinances may be confusing and outdated. Zoning laws are in place to plan land usage to benefit the local home and business owners and provide a safe and clean environment. Urban agriculture is a relatively new concept that may not have legal precedence under local zoning laws, especially for aquaponics. Many municipalities still need to expand or loosen their definition of urban agriculture to include aquaponics, particularly within a warehouse/industrial setting where mixed uses may include agriculture, tourism, and on-farm sales (Tomlinson, 2015).

Research Problem and Goals

The challenges to aquaponic growers are broad and vary by stakeholder group. Challenges identified in this literature review span the topics of economic viability, consumer perceptions of products, access to financing options, local climate and regulatory conditions, operations and management, educational administrative hurdles, lack of knowledge, information quality and access, regulations and certifications. As the aquaponics industry grows and matures it is sensible to track the challenges experienced and trends in production to project a successful way forward for growers. This dissertation research was designed to:

1. Document challenges and trends and assess needs of aquaponic stakeholders.
2. Assess importance, knowledge, and accessibility levels of aquaponic stakeholders in various competency areas and prioritize topics for content development.
3. Evaluate the usage patterns and quality of informational resources by aquaponic stakeholders and recommend formats and topics for creation.
4. Document current production practices of aquaponic stakeholders.
5. Analyze the relationships between various production scale measures including area, volume, production output, and investment.

Methods

An online aquaponic industry survey was created using the Qualtrics (Provo, Utah, USA) to collect data from aquaponic stakeholders using methods recommended by Dillman (2007) and Fowler (2009). The survey was externally reviewed by the Aquaponics Association to validate the questions and format, then reviewed and approved by Auburn University's Institutional Review Board (IRB Protocol No: 19-544 EX 1912). More on methods will come in each chapter.

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Table 1.1. The hype ratio of various agricultural search terms.

Search Keyword	Google Search Results	Google Scholar Search Results	Hype Ratio*
Aquaponics	15,400,000	11,000	1,400:1
Hydroponics	51,000,000	80,000	637:1
Agriculture	1,500,000,000	4,990,000	300:1
Sustainable Agriculture	555,000,000	3,000,000	185:1
Horticulture	70,700,000	2,290,000	31:1
Aquaculture	33,900,000	2,630,000	13:1
Recirculating Aquaculture	639,000	52,400	12:1

* Hype ratio = [Google search results / Google scholar search results]

Chapter 2

Challenges Experienced by Aquaponic Hobbyists, Producers, and Educators

Abstract

Aquaponics is a segment of agriculture that integrates fish and plant production. Few published accounts of industry practices and trends exist; thus, this research fills a void by documenting challenges experienced by aquaponic stakeholders. Using an online survey tool, hobbyists (n = 81), producers (n = 117), and educators (n = 75) were asked to provide their top three challenges experienced in aquaponics. Challenge responses were broadly categorized as OM- operations and management, FLSD-facilities, location, and system design, KER-knowledge and educational resources, F-funding, EV-economic viability, PC-plant culture, MD-marketing and distribution, FC-fish culture, HF-human factors, and RC-regulations and certifications. The top 5 challenges were FLSD, OM, PC, KER, and FC for Hobbyists, OM, FLSD, F, KER, and MD for producers, and OM, FLSD, KER, HF, and F for educators. Less experienced growers (< 5yrs) reported KER as a challenge 5% frequently, while more experienced growers (>5 yrs) reported OM (3.4%), EV (2.5%), MD (2.4%), and RC (1.3%) more frequently. Regulatory challenges included 1-aquaculture/exotic species permitting, 2-zoning/construction/building permits, 3-certification/processing/food safety, 4-excessive bureaucracy/unclear policies, 5-institutional/school policy, 6-cost of permits/certifications, 7-effluent discharge. Training opportunities will assist researchers, educators, policy makers, and other supporting groups in facilitating the growth and success of local and regional aquaponic industries by nourishing educational efforts to address and deliver these needs.

Introduction

Aquaponics is a segment of agriculture integrating fish and plant production in a symbiotic process. Methods of production range from low-tech outdoor field crop irrigation with aquaculture effluent (Palm et al., 2018; Pickens et al., 2020; Pattillo et al., 2020) to high-tech, controlled environment agriculture using recirculating aquaculture systems and hydroponic production techniques (Suhl et al., 2016 & 2018; Palm et al., 2018; Goddek and Körner, 2019). There is substantial interest in aquaponics because of the variety of production methods and its adaptability to various climates and locations (Goddek and Körner, 2019). Product quality, rate of plant/fish growth, adaptability to rural/urban environments, and resource use efficiency are touted as benefits of aquaponics (Tomlinson, 2015; Goddek et al., 2015; Pattillo 2017a). However, to be successful, individuals must possess necessary knowledge and skills to successfully manage an integrated aquaculture and plant production facility (Greenfeld et al., 2020a). The interdisciplinary nature of aquaponics can make the learning curve steep for many and lower the likelihood of success (Hart et al., 2013; Goddek et al., 2015; Turnsek et al., 2020).

According to Love et al. (2014), the current aquaponic industry consists of hobbyists, educators, producers, and supporting groups (e.g. public agencies, equipment suppliers, community groups, processors, transporters, feed manufacturers, and others). Most practitioners are relatively new to aquaponics (Love et al., 2014) and are in a continual state of information gathering and learning through trial and error (Mchunu et al., 2016; Greenfeld et al., 2020a). With limited published accounts of industry practices and trends, it is important to define and document current stakeholder group needs and challenges in order to use this information to assist others who are planning to begin an aquaponic operation (Konig et al., 2018; Turnsek et al., 2020). Further, the goals and needs of individuals vary by stakeholder group, making it beneficial to characterize them accordingly. Developing an understanding of the nature and extent of the gaps in stakeholder fluency is essential to filling them and is the focus of this research.

We surveyed hobbyists, producers, and educators. Study goals were to: 1) identify challenge areas experienced by stakeholders; 2) assess trends and differences in challenges experienced by different stakeholder groups; and 3) provide an assessment of stakeholder needs and potential solutions. Results are relevant to researchers, teachers, and Extension educators looking to develop educational resources for newcomers.

Materials and Methods

An online survey tool was developed with a composite of original and adapted questions from previous research (Love et al., 2014; Villarroel et al., 2016) using the Qualtrics (Provo, Utah, USA) software to collect data from aquaponic stakeholders using methods recommended by Dillman (2007) and Fowler (2009). The survey was externally reviewed by the Aquaponics Association to validate the questions and format, then reviewed and approved by Auburn University's Institutional Review Board (IRB Protocol No: 19-544 EX 1912). Survey advertisement included an information letter explaining study objectives, data collection process, participant rights and confidentiality. The minimum age to participate was 18 years. To ensure anonymity, data is only presented in aggregate form.

Electronic survey dissemination occurred from December 10, 2019 to June 4, 2020, utilizing a variety of advertising methods including email lists of various aquaculture Extension networks and professional aquaculture/aquaponic societies, as well as social media groups focused on aquaponics. A snowball advertising method (Browne, 2005; Baltar and Brunet, 2012; Love et al., 2014) was used, encouraging participants to share the survey amongst their peers. The anonymous nature of data collection and snowball advertising method using social media platforms prevented an accurate response rate calculation.

Respondents selected their stakeholder group as either hobbyist, producer, or educator. The survey asked respondents to provide their top three challenges in an open text response format. The survey also asked if they had encountered any regulatory constraints regarding their aquaponic operation. If yes, respondents specified the regulatory constraints encountered. Analogous questions were asked pertaining to permit or license requirements for their aquaponic operation. Two investigators synthesized the text responses independently to develop theme areas that were then merged to create final categories for analysis.

Data were compiled in Qualtrics and exported for analysis in SPSS Statistic 26 (IBM, Armonk, NY, USA) and figures were developed in Excel (Microsoft 360, Redmond, WA, USA). Frequencies and proportions (e.g. percentage) were used to generalize stakeholder responses. In this study ‘N’ is used to denote the total respondents answering a given question, while ‘n’ is the number of respondents answering the question from each stakeholder group.

Results

Response participation varied by question, as noted in the tables and figures. Table 1 provides demographic information and Table 2 provides information of the background, experiences, and production practices of each stakeholder group.

Challenges experienced by respondents are summarized into ten categories as a composite of all stakeholder groups (Table 3), with relative frequency broken down by stakeholder group (Figure 1). Challenge categories included 1) operations and management (OM), 2) facilities, location, and system design (FLSD), 3) knowledge and educational resources (KER), 4) funding (F), 5) economic viability (EV), 6) plant culture (PC), 7) marketing and distribution (MD), 8) fish culture (FC), 9) human factors (HF), 10) regulations and certifications (RC). We defined primary challenges as those experienced by >50% of respondents, and secondary challenges as reported by 30-50% of respondents in their respective group. Hobbyists primary challenges included FLSD and OM, producers' primary challenge area was in OM, while educators had no predominant challenge. Secondary challenges for hobbyists included PC and KER, while producer secondary challenges included FLSD, F, KER, and MD, and for educators, it was OM, FLSD, and KER. Growers with >5 yrs of experience reported OM 3.4% more, EV 2.5% more, and MD 2.4% more, and RC 1.3% more frequently than those with < 5 yrs of experience (Figure 4). Alternatively, growers with < 5 yrs of experience reported KER challenges 5% more frequently than those with > 5 yrs of experience (Figure 4).

The percentage of stakeholders experiencing regulatory and permitting challenges is presented in Figure 2, with the relative frequency of regulatory challenge categories experienced by group in Figure 3. Out of 246 respondents, 34% (n = 84) indicated encountering regulatory constraints to operating their aquaponics system. Regulatory challenge categories included 1) aquaculture/exotic species permitting, 2) zoning/construction/building permits, 3) certification/processing/food safety, 4) excessive bureaucracy/unclear policies, 5) institutional/school policy, 6) cost of permits/certifications, and 7) effluent discharge. There was often more than one regulatory issue provided per respondent. Hobbyists and educators most frequently cited aquaculture permitting, specifically for housing exotic fish species like tilapia as a regulatory constraint. Crops with regulatory concerns, like Tilapia and cannabis, were grown by 69% and 6% of respondents, respectively. Producers cited challenges with certifications and food processing/safety concerns most commonly.

Permits and certification requirements included USDA organic certification, Global Good Agricultural Practices (GAP), Food Safety Modernization Act (FSMA) (US Food and Drug Administration, FDA), interstate transport of fish and veterinary inspections (US Fish and Wildlife Service, USFWS), well drilling and land impinging on federal waters (US Army Corp of Engineers, COE), state aquaculture permits (DNR), wastewater discharge (US Environmental Protection Agency, EPA; National Pollutant Discharge Elimination System, NPDES), business licenses (state/local health departments) and local ordinances (land use zoning boards).

Discussion

Challenges experienced by aquaponic stakeholders should be tempered with the notion that many beginners start with grand ideas of sustainability, profitability, and a system that virtually runs itself. Although promoting this image can be a good sales tactic for manufacturers and suppliers, it may be detrimental to the aquaponic industry. Obtaining technical proficiency in optimizing fish and plant production, controlling the growing environment, navigating legal and business aspects, and doing all this in a time-efficient manner can be difficult, especially for beginners. Several studies (Tyson et al., 2011; Hart et al., 2013; Love et al., 2014 & 2015a; Quagrainie et al., 2017; Villarroel et al., 2017; Brewer, 2019; Silva et al. 2019; Greenfeld et al. 2020a; Turnsek et al., 2020) have reported that newcomers are challenged frequently by daily operational tasks. The fact is that aquaponics takes time and effort to master (Greenfeld et al., 2020a). Aquaponics is not an autonomous system, particularly for low-tech systems without automation (Kyaw, 2017). The majority of stakeholders spent up to 20 hours per week working with their system, with producers spending over 60 hours per week at times.

Operations and Management

As an operator matures into a seasoned expert, they inevitably find that careful management of energy, labor, water and other plant and fish inputs are necessary for production efficiency and minimizing production costs (Love et al., 2015b; Quagrainie et al., 2017). We found the majority of respondents experienced operational challenges, with 3.4% greater frequency at greater experience levels (Figure 4). Tyson et al. (2011) suggested that operations and management factors like optimizing the production environment (e.g. water chemistry, pH, biological filtration, temperature, and light), maximizing production outputs (e.g. fish and plants), and minimizing effluent discharge into the environment are the top sustainability challenges for aquaponic producers.

Access to inputs was a constraint for several respondents in our study outside the US, similar to Silva et al. (2019), who reported access to inputs for constructing and operating a successful aquaponic system was the top concern for many practitioners in Brazil. Input limitations included feed, fingerlings, equipment, shipping cost, and import tax.

Hart et al. (2013) reported top educator challenges were in the areas of 1) technical difficulties encountered while planning, building, and running the system; 2) space, infrastructure, and administrative support; 3) restrictions associated with operating in a school setting; and 4) finding time and labor to run and maintain the system, especially through summer breaks and holidays. Physical modifications to the aquaponic system (e.g. size, plumbing, growing systems, equipment, etc.), seeking community connections and support for various aspects of running the system, developing a passion for aquaponics, seeking mentorship, and developing personal expertise through hands-on experience are all ways to overcome operational challenges (Hart et al., 2013).

We found that finding skilled laborers is a challenge for producers because there are very few schools, mentoring opportunities or workshops that offer relevant on-going training; thus, employees are trained frequently on the job. Programs to help aquaponic newcomers, especially in the startup phase may be helpful. The Land Grant Universities, community colleges and high school programs could train more students in aquaponics to fill the roles of skilled workers, entrepreneurs, consultants, manufacturers, suppliers, teachers, researchers, and extension agents.

Facilities, Location, and System Design

Understanding local climate effects (e.g. tropical vs. temperate climate) and how they play into efficient system design, fish/plant choices, production costs, expected sales price, and profitability are critical to success (Rakocy et al., 2004; Engle 2015; Love et al., 2015c; Goddek and Körner, 2019). Environmental control for plant production requires providing appropriate light, temperature, humidity, airflow, integrated pest management and other factors that influence plant production. Out of season production of vegetables and leafy greens can attract a higher price, which is an advantage for protected culture or controlled environment growers, assuming production cost is below the sales price. Ideally, local winter production of vegetable and fish products at competitive cost and selling prices would fulfil the promise of aquaponics to supply fresh products when other local produce is not available.

In the temperate and subtropical regions of the US (e.g. plant hardiness zones 4-9), the use of greenhouses and other controlled environments are critical to year-round production (Pickens and Danaher, 2016). These zones present production challenges like the need for supplemental heating and light systems in the winter, but also cooling and shading in the summer. Heating and lighting costs associated with out-of-season production can be cost prohibitive. Love et al. (2015b) found that in January (winter), the energy cost for producing crops averaged $55/kg compared to $1/kg in May through August (summer). The impact of colder climate regions on aquaponic systems are higher infrastructure and equipment investment, higher operating expenses related to heating (electricity, propane) and selection of fish species adaptable to local conditions (Love et al., 2015b; Ghamkhar et al., 2020). Environmental impacts of these additional inputs can contribute to climate change, environmental pollution, ocean acidification, and eutrophication (Ghamkhar et al., 2020).

Knowledge and Educational Resources

Knowledge was identified as a challenge by approximately one third of all respondents, although knowledge deficiencies tend to vary by stakeholder background (Villarroel et al., 2016). Love et al. (2014) found aquaponic practitioners felt very confident about water chemistry and plumbing, fairly confident about fish and plant husbandry, and marginally confident that they knew regulations regarding fish sales. Greenfeld et al. (2020a) found that over half (59%) of recent adopters have some prior knowledge, yet 41% still struggled in their first year of operation. Our results show a 5% decrease in KER challenges experienced from growers with > 5 yrs experience. Mchunu et al. (2018) reported that although self-perceived grower knowledge may be relatively high, their troubleshooting skills may be inadequate. This phenomenon is called the Dunning-Kruger effect, where individuals are ignorant of their own ignorance (Dunning, 2011). Often, the primary interest of growers is skewed toward either fish or plants based on their background. Villarroel et al. (2016) reported that knowledge of fish diseases, plant nutrition, and fish-processing regulations was relatively high for growers, however, knowledge of plant pests was much lower, relating to the respondent's primarily fish production background.

Reliable information sources can be sparse (Turnsek et al., 2020). Misinformation was a specific challenge highlighted by respondents. Newcomers are susceptible to the negative impacts of misinformation because they do not have the working knowledge to distinguish good from bad information. Even from the home and garden store perspective where many people would purchase their plumbing and other inputs and might seek advice, employees are not knowledgeable about aquaponics (Campbell et al., 2015).

According to Villarroel et al. (2016), commonly used information resources include university, online, or printed documents, followed by workshops, with very few seeking information from government agencies.

Education of farmers and consumers is a necessity for the future sustained success of the aquaponic industry (Goddek et al., 2015). Quality, research-based information should become an emphasis of Land Grant University aquaponic programs, with a comprehensive suite of research publications, demonstration and training facilities, online videos, fact sheets and trainings conducted by each State's extension system. Workshops must be catered to the individual needs of each stakeholder group including length, location, cost, content, and rigor. Ideally, the topic areas of system cost, capital and equipment needs, water source, plant and fish production specifics, pest/disease control, watering, harvesting, processing and marketing should be included.

Funding

Access to capital for startup costs like facility construction, land purchase, operating loans for purchasing fish and plant inputs or paying utilities bills were the most frequently stated funding issues. The majority of participants used personal funds to support their operation. Producers had the most diverse combination of funding sources (n = 6), while educators made greatest use of grant opportunities. Aquaponic operations are often seen as high-risk ventures making them difficult to finance, forcing producers to use personal funds and limiting industry growth (König et al., 2018). Lack of financing options are due to general unfamiliarity with aquaponics as well as few documented examples of profitable businesses (Engle, 2015). Aquaponic business viability is difficult due to a high initial investment for the greenhouse, aquaculture and plant system components and ongoing operating costs (Quagrainie et al., 2017). It has been suggested that a minimum facility footprint of 1,000 m^2 is necessary to achieve profitability in Europe (Junge et al., 2017). The cost of such a large facility is likely in the hundreds of thousands of dollars (Bailey et al., 1997), a price tag that severely limits entry into the commercial industry. This is exacerbated by the fact that bank loans have been virtually inaccessible to aquaponic farmers (Villarroel et al., 2016; Turnsek et al., 2020). As seen in this study and others (Love et al., 2015; Villarroel et al., 2016), producers have little choice but to use their own personal funds or find private investors. However, about 20% of producers in this study reported using loans, which may indicate the beginning of a change in acceptance of aquaponics by lenders.

Access to capital must be addressed, but loaning agencies require collateral to cover the loan amount which would be lost if the borrower's operation fails (Engle, 2010). Government-backed loans may be an opportunity to reduce this risk and allow farmers to get the financing they need (Brewer, 2019; Greenfeld et al., 2020a), but again government loans are not free and must be paid back. Loan opportunities will be needed for the industry to grow and may only be achieved when the perceived risk to loan agencies is lower and below their threshold levels (König et al., 2018). Increased training in core competency areas should ensure higher success rates, and training program certification can serve as evidence to bank officers. A detailed business plan can help in obtaining loans and promote farming success by making growers think through potential business obstacles (Engle and Stone, 2013). Once successful business models are established aquaponic businesses will be welcomed by loan agencies.

Economic Viability

Economic viability challenges centered around high production costs (infrastructure, rent, inputs and utilities), appropriate production scale, lack of successful business models, and overall profitability. The cost of producing fish and plants and expected selling prices should be researched and addressed during business planning, well before beginning system construction or operation. Our finding show that more experienced growers tend to be more frequently challenged by economic viability (Figure 4), which becomes more important as startup funds are depleted and the system must perform well financially on its own. Many inputs and infrastructure are too high while market prices are too low to make a profit. System scale directly impacts output production cost per unit, and aquaponic systems are often inappropriately scaled to operate profitably (Xie and Rosentrater, 2015; Quagrainie et al., 2017). Emerging industries, such as aquaponics, experience an early formation period characterized by a lack of meaningful product prices or clear market demand (König et al., 2018). These issues vary by location and market segment, making business planning difficult (Greenfeld et al., 2020b). Newcomers are cautioned that aquaponics is in this high-risk formation stage for entrepreneurs and investors currently, and this period could last for many years (König et al., 2018).

Alternative income sources such as agritourism, educational opportunities, and selling non-food products (e.g. compost, ornamental plants/fish, etc.) related to aquaponics is a common practice to generate a profit (Love et al., 2015a; Junge et al., 2017). Expanding aquaponic production beyond the greenhouse into field crop conditions could also be a means of increasing production and cash receipts without high additional infrastructure costs (Pattillo et al., 2020). Seasonal field crop production could be of particular benefit during summer months when tilapia feeding rates and waste generation are at their peak, eliminating extraneous effluent discharge. Additionally, summer greenhouse temperatures are often too high during the summer for certain plant varieties and competition from traditional field-grown crops are at their highest, causing sales prices to plummet (Pickens et al., 2016). Expanded seasonal outdoor production could help level the playing field for some aquaponic producers (Pattillo et al., 2020).

Plant Culture

Primary plant culture challenges dealt with optimizing production from determining which varieties to grow and how to protect them from pests, diseases, and nutrient deficiencies to harvesting logistics and processing regulations. Plant varieties, growing environment, and production systems must be compatible to optimize production (Pickens et al., 2016). Environmental control for plant production requires providing appropriate light, temperature, humidity, airflow, integrated pest management and other factors that influence plant production. The majority of participants were operating coupled aquaponic systems, which generally are not amenable to the use of pesticides, whereas decoupled systems are. Decoupled systems also allow for the use of nutrient supplements, temperature, and pH modification without endangering the fish or biofilter. Since 87% of respondents in our study used coupled systems (13% used decoupled systems), good information on decoupled systems needs to be available so newcomers can weigh the pros and cons of this system compared to the coupled system (Monsees et al., 2017).

Marketing and Distribution

Marketing and distribution challenges identified most often refer to positioning the product in the marketplace, understanding consumer preferences, determining appropriate pricing, educating consumers, advertising, selling, and distributing products to customers. Marketing was a major challenge for producers with respect to market analysis, price competition, product promotion, and consumer acceptance, and was a more frequently recognized issue for more experienced growers (Figure 4), especially producers (Figure 1). Marketing requires understanding customer preferences and forging a connection to clientele that may be willing to pay a premium for sustainably produced products (Short et al., 2018). Several studies have shown consumers are generally unaware of aquaponics (Zugravu et al., 2016; Short et al., 2017; Miličić et al., 2017; Greenfeld et al., 2020b). This lack of consumer recognition can negatively affect consumer willingness to pay higher prices for aquaponic products (Abbey, 2018; Yee, 2020).

Aquaponic products are substitutes for conventionally grown products; therefore, price competition can be a serious challenge to entering a marketplace (Engle, 2015; Greenfeld et al., 2020b). Competition with market substitutes like field-grown and imported produce and fish prevents the acquisition of an economically sustainable scenario for many producers. Niche ethnic markets are often targeted for live fish sales because prices are generally high, but this market can be easily saturated (Engle, 2015). Large-scale tilapia production can have marketing issues due to large volumes of inexpensive, frozen tilapia imports that come to the US each year. Thus, at industrial scales a US aquaponic producer may need to consider selling their tilapia product at a low price, especially if it is a live product, as many consumers do not want to filet their fish (Engle, 2015).

Fish Culture

Fish culture challenges focused on lack of ready access to fish fingerlings of the appropriate size and species for stocking, feeding efficiency, managing fish health, and processing for markets. Selecting an easy-to-grow, sought-after fish species that is adapted to local conditions, locally available, disease resistant, and has a good market value is a challenge. Tilapia is the most commonly grown fish species in aquaponics. While investigating commercial aquaponic systems, newcomers would be wise to listen to Love et al. (2014) who recommended diversifying the fish species beyond tilapia. While tilapia is a relatively easy fish to grow, it does require warm water temperatures and is an exotic species that could present regulatory hurdles. Additionally, food-fish sales are subject to FSMA and local health department regulations. Love et al. (2014) also recommended that newcomers consider raising and selling non-food fish, such as high value ornamental species (e.g. koi). This route requires growers to be quite knowledgeable about fish diseases and have testing facilities to be sure live ornamental fish are healthy before selling and shipping. Live ornamental fish sales allow growers to bypass food safety and processing regulations, but interstate transport laws may apply (Engle and Stone, 2013).

Human Factors

Human factor challenges such as personal motivation factors (e.g. self-starting and time management), security, community and political support, food security and environmental concerns were a low-level challenge for respondents, although more common for educators. Connections with social and professional aquaponic groups can provide a support network for new growers when they become discouraged due to the initial learning curve. These associations can also be influential in public education and affect government policy. Hart et al. (2014) encouraged educators to manage their expectations and plan for success in aquaponics by preparing for operational challenges, particularly with staffing. Production yields may be high for aquaponics, but not significantly different from hydroponics (Ayipio et al., 2019). Although aquaponics can be an effective teaching tool (Junge et al., 2014; Genello et al., 2015; Schneler et al., 2015; Clayborn et al., 2017), there are challenges with constructing and maintaining the system in the school environment that increase the level of complexity of maintenance and responsibility of caretakers (Hart et al., 2013 & 2014). When factoring in the cost and effort required to maintain an aquaponics system, those that desire a low maintenance system may want to consider a soil-based garden or hydroponic system instead (Love et al., 2015c).

Regulations and Certifications

Regulation and certification challenges dealt with FSMA, GAP, and USDA Organic compliance, and obtaining necessary permits, licenses, zoning and land use classifications. This is an important area for the aquaponic newcomer to research before beginning a system, yet more experienced producers reported this challenge more frequently (Figure 4), which is likely because they become more exposed to them and have greater awareness over time. Regulatory issues associated with aquaponics are broad, with multiple agencies regulating water quality, interstate transport of fish, food safety and processing, business, land use and zoning at the local, state, and federal level (Engle and Stone, 2013). Not only do farmers need to be able to run the system, which is complicated in itself, they also have to operate in an environment of increasing scrutiny of agriculture practices and products (Engle and Stone, 2013; Goddek et al., 2015). According to the US EPA (2020), permitting requirements for aquaculture effluent discharge from Concentrated Aquatic Animal Production (CAAP) facilities begin at production rates of 20,000 lbs/yr for coldwater fish (e.g. trout) and 100,000 lbs/yr for warmwater fish (e.g. catfish and tilapia). Luckily, the vast majority of aquaponic producers fall below this threshold. Additionally, facilities that discharge less than 30 days per year are exempt from the CAAP point source categorization (US EPA, 2020). Fortunately, due to the water and nutrient-efficient nature of aquaponics, an exemption under this rule is obtainable for smaller and well-designed facilities.

Consumers often judge the quality of produce by certification labels such as being ‘organically’ grown. Compliance with certification standards like GAP or organic can be challenging, and as certification standards change, they may not be available to aquaponic growers (Kledal et al., 2019). Various markets react differently to aquaponic produce regarding willingness to pay and consumption of these products (Greenfeld et al. 2020b). Therefore, production strategies, particularly operational scale, should be aligned with local market dynamics.

Although aquaponics can be practiced in virtually any location, there are often issues with zoning restrictions that must be dealt with on a local level. In this study, background setting affected the level of zoning restrictions and permitting requirements, with urban and industrial settings being the most rigorous. Homeowner associations (HOAs) and local ordinances were also found to be restrictive to aquaponic activities in suburban and urban settings. Rural settings were least restrictive. Turnsek et al. (2020) found lower levels of commercial aquaponic activity was likely when there are rigorous compliance issues, especially in conjunction with voids in regulatory precedence for commercial aquaponic operations. Because many newcomers to aquaponics may be first time business owners as well, local zoning ordinances may be confusing and/or outdated. Zoning codes vary by municipality and many have not expanded or loosened their definition of urban agriculture to include aquaponics, particularly within a warehouse/industrial setting. A mixed-use classification is likely necessary to appease the many personal, agricultural, and commercial aspects of aquaponics that stakeholders may require (Tomlinson, 2015).

Educators encountered institutional policies for ethical animal usage and serving aquaponic produce to students. The Institutional Animal Care and Use Committee (IACUC) monitors the research use and treatment of animal subjects at universities, government, and other research facilities in the US. Policies and justification for animal use are stringent. However, since fish are the nutrient engine of the aquaponic system and are rarely manipulated in a deleterious manner, their use is more easily justified. IACUC considerations do not apply to private fish production, however animal rights groups often focus on confined rearing of fish. Food safety and seafood processing standards are also stringent, requiring processing facilities to meet the Hazard Analysis and Critical Control Point (HACCP) certification criteria for sanitation (Hollyer et al., 2009; Fox et al., 2012; FDA, 2020). These requirements usually include surfaces that can be easily disinfected, measures to prevent food contamination, and protective equipment for employees, but also include guidance on allergens, toxins, pathogens, parasites, and aquaculture drugs (FDA, 2020).

Conclusions

The aquaponics industry could benefit from streamlining and standardization of practices and guidelines for success (Konig et al., 2018; Palm et al., 2018; Greenfeld et al., 2019). The current study sheds light on the challenges experienced by stakeholders. We found that there are numerous and varied challenges affecting this stakeholder group. The challenge areas expressed by respondents serve as a needs assessment for training and educational resource development. Difficulties with daily operations were most commonly mentioned, followed by factors related to the facility and obtaining relevant knowledge. The initial learning curve for aquaponics is steep because of the integrated systems and skills required. We recommend the development of informational resources and training opportunities to enhance the learning timeline of enthusiasts. Holistic, hands-on aquaponic training workshops, perhaps led by Cooperative Extension programs, can instill participants with the confidence to perform daily activities and troubleshoot when issues arise. Training levels from single to multi-day workshops, as well as full undergraduate and graduate degree programs, and on-farm internships could be integrated to assist stakeholders at different levels of interest. Traditional delivery methods including trainings, workshops, meetings and reliable, quality research-based information sources may provide opportunities for participants to address challenges. Unfortunately, the ability to provide these programs is undermined by the lack of full-time extension employees dedicated to aquaponics and lack of institutional support for extension programs (Swann and Morris, 2001), leading to unsustainable training programs. Online instructional opportunities like a monthly webinar series or distance education workshops could be used improve access to training.

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Table 2.1. Demographic identifiers of hobbyists, producers, and educators responding to the survey.

Demographic Category		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Stakeholder Group		105	25	156	37	117	28
Age Group	18-24	1	2	1	1	0	0
	25-34	5	7	12	15	5	9
	35-44	10	15	15	19	11	19
	45-54	15	22	15	19	14	24
	55-64	20	29	25	32	20	34
	65-74	11	16	10	13	7	12
	>75	6	9	1	1	1	2
	Total	68	100	79	100	58	100
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	65	100	75	100	59	100
Education	≤ High school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	66	100	77	100	61	100
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	66	100	74	100	57	100
Ethnicity	Asian	4	5	4	5	3	5
	Black	1	2	7	9	6	10
	Hispanic	1	2	0	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	59	78	38	63
	Other	1	2	0	0	5	8
	Undisclosed	5	7	6	8	3	5
	Total	68	100	76	100	60	100
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	68	100	71	100	59	100
Primary Income Source	Aquaponics	0	0	21	28	2	3
	Other	68	100	53	72	56	97
	Total	68	100	74	100	58	100

Table 2.2. Experience, effort, knowledge, system style, setting, funding, development and intent of aquaponic stakeholders.

		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Years of Aquaponic Experience	< 1 year	25	24	29	19	16	14
	1-2 years	22	21	31	20	21	18
	3-5 years	35	34	38	25	30	26
	6-10 years	18	18	38	25	31	27
	11-20 years	3	3	15	10	10	9
	>20 years	0	0	4	3	9	8
	Total	103	100	155	100	117	100
Weekly Time Spent	0-10 hours	61	71	38	31	47	55
	11-20 hours	20	23	23	19	25	29
	21-30 hours	4	5	18	15	5	6
	31-40 hours	0	0	20	16	5	6
	41-60 hours	1	1	18	15	2	2
	> 60 hours	0	0	6	5	1	1
	Total	86	100	123	100	85	100
System Design	Self-Designed	93	97	94	73	65	74
	Professional Designed	3	3	35	27	23	26
	Total	96	100	129	100	88	100
System Style	Coupled	85	92	114	84	75	85
	Decoupled	7	8	21	16	13	16
	Total	92	100	135	100	88	100
Climate Zone	Polar	2	3	6	6	1	2
	Temperate	22	31	34	35	19	32
	Subtropical	40	56	48	50	27	45
	Tropical	7	10	9	9	13	22
	N	71		97		60	
Funding Source	Personal Funds	82	96	98	78	36	46
	Private Investment	0	0	35	28	7	9
	Government Grants	0	0	19	15	33	42
	Private Grants	0	0	16	13	17	22
	Loans	0	0	25	20	2	3
	Credit/Financing	5	6	10	8	2	3
	N	85		126		79	
Background Setting	Rural	46	47	79	54	31	31
	Suburban	34	35	25	17	35	35
	Urban	17	17	37	26	34	34
	Industrial	1	1	4	3	1	1
	Total	98	100	145	100	101	100
Development Stage	Researching	16	17	12	9	20	22
	Planning	17	18	38	28	14	16
	Constructed	6	6	8	6	7	8
	Operational	56	59	79	58	48	54
	Total	95	100	137	100	89	100

* N is the number of participants that responded when there was more than one selection option

Table 2.3. Challenge categories provided by aquaponics survey respondents.

Rank	N	Category	Summarized Challenge Responses
1	144	Operations and Management (OM)	Labor/staffing; balancing fish and plants; sourcing/availability of inputs; resource management (energy, electricity, etc.); monitoring operations; water quality; nutrient balance; mineralization; algae control; cleaning; power failure; record keeping; system startup/maintenance; optimizing production; marine aquaponics
2	138	Facilities, Location, and System Design (FLSD)	Growing environment/greenhouse; recirculating aquaculture system; plumbing; construction; water filtration; solid waste removal; equipment failure; technology; system efficiency optimization; water access; equipment; heating/cooling; environmental control; automation; location; space; land; climate
3	87	Knowledge and Educational Resources (KER)	Knowledge; learning curve; availability of training opportunities; availability, quality, and organization of educational resources; public education; grower networking; research; product development; misinformation; reputable and disreputable suppliers
4	74	Funding (F)	Access to money; capital; financing; funding sources for investment, construction and operating expenses
5	55	Economic Viability (EV)	Production cost; profitability; lack of viable business models; return on investment; startup cost; energy cost; system scale; system cost
6	53	Plant Culture (PC)	Species selection; growth rates; production output; nutrient deficiencies; integrated pest management; pests; diseases; processing
7	51	Marketing and Distribution (MD)	Market analysis; marketing; sales; price; distribution; consumer acceptance; product and technology promotion; educating others; consumer education; price competition
8	45	Fish Culture (FC)	Feed and nutrition; species selection; husbandry; health; growth; processing
9	42	Human Factors (HF)	Getting started; time availability and management; personal health; theft and security; motivation; confidence in growing; teacher adoption; community and government support; social views; stakeholder partnerships; food security; environmental sustainability
10	41	Regulations and Certifications (RC)	Permits; licenses; regulations; certifications (Global GAP and Organic); food safety

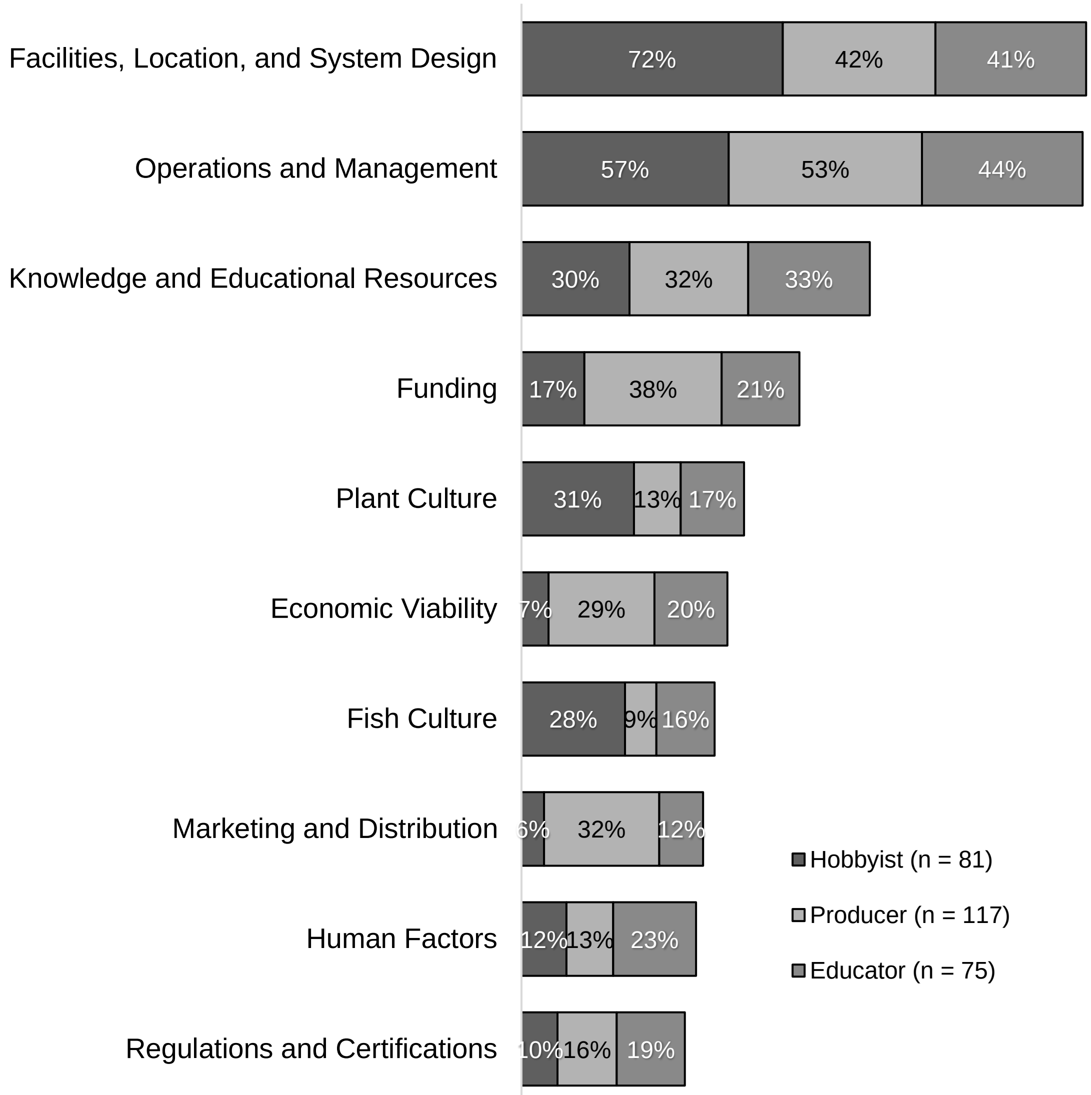

Figure 2.1. Proportion of aquaponic hobbyists, producers, and educators reporting challenges in various aspects of aquaponics operations. Percentages represent the proportion of each stakeholder group experiencing that specific challenge. Ranking is based on the cumulative percentage of respondents in each group and class.

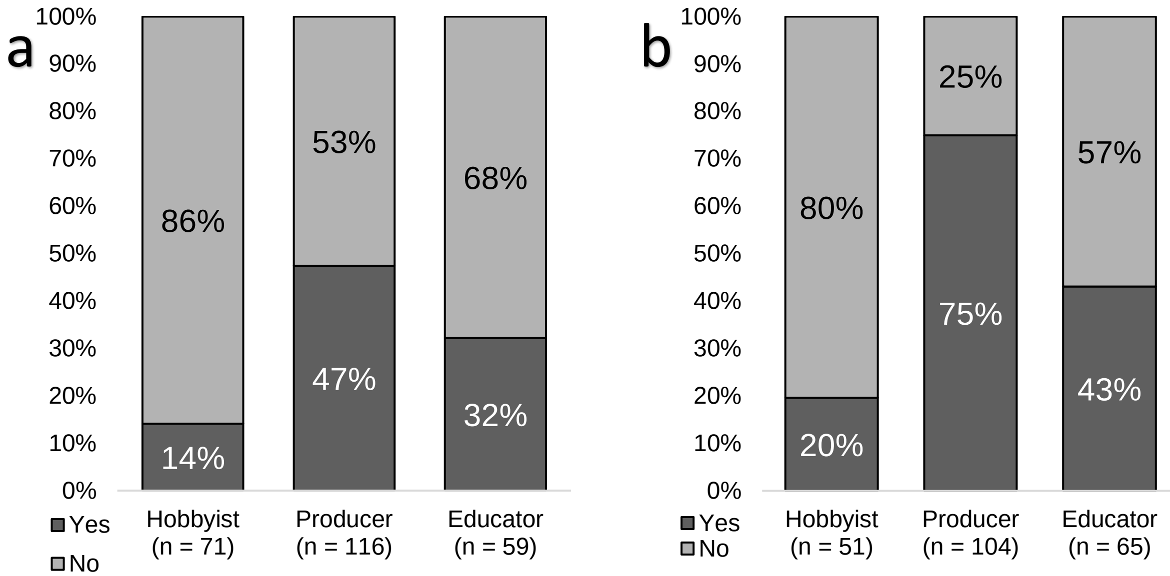

Figure 2.2. Percentage of aquaponic hobbyists, producers, and educators that experienced a) regulatory roadblocks and b) permitting or licensing requirements.

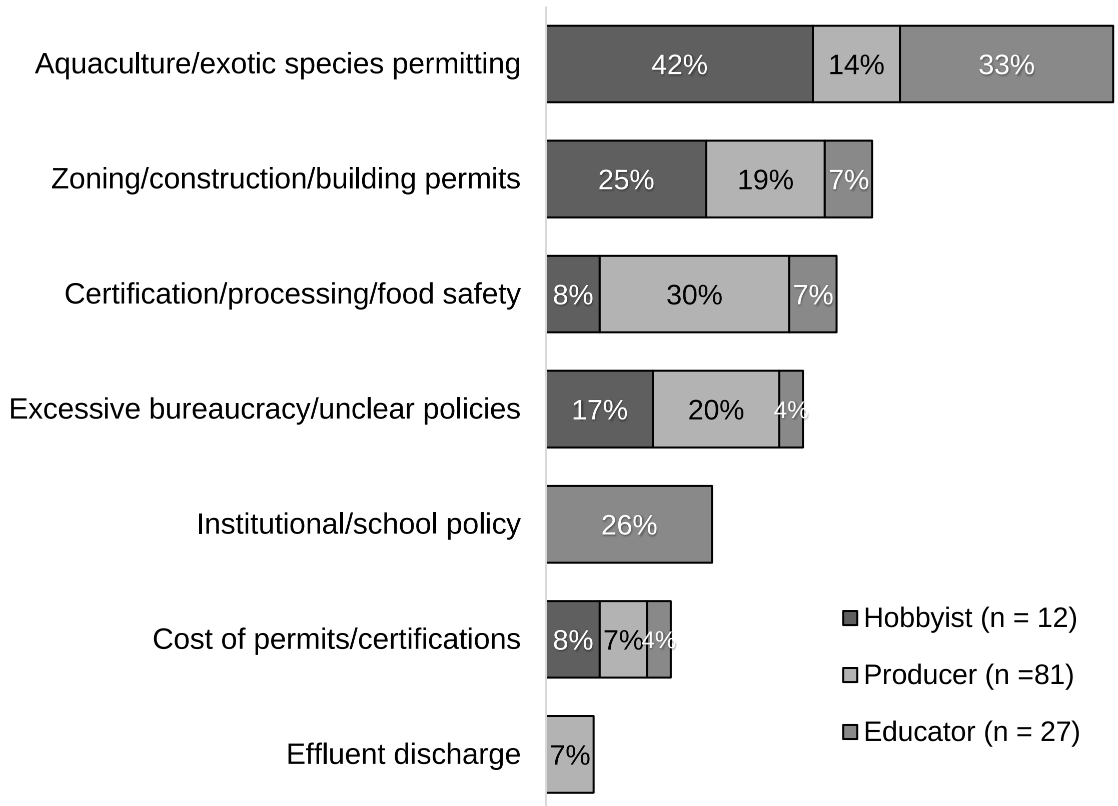

Figure 2.3. Regulatory challenges experienced by aquaponic hobbyists, producers, and educators. Percentages represent the proportion of each stakeholder group experiencing that specific challenge. Ranking is based on the cumulative percentage of respondents in each group and class.

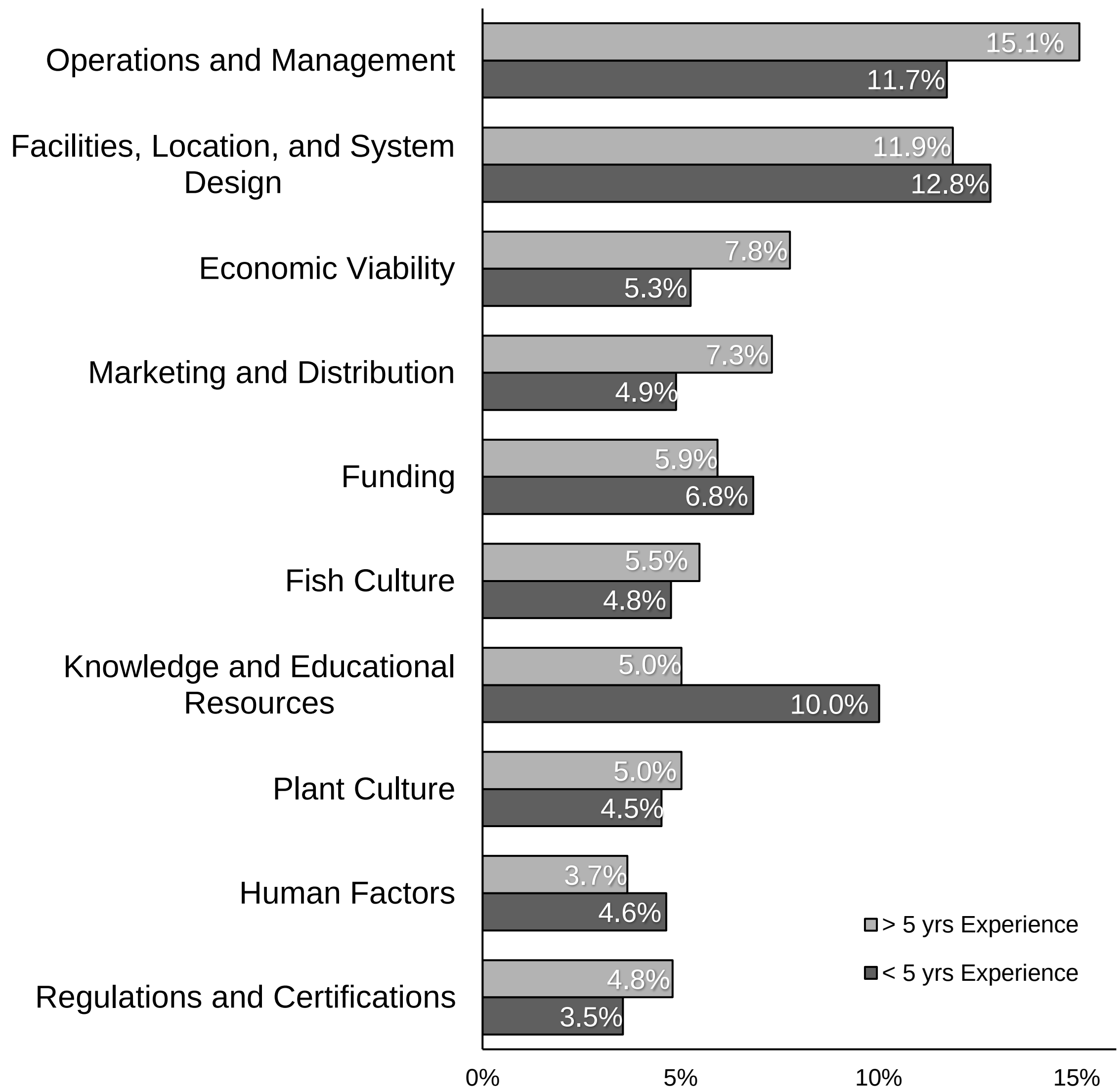

Figure 2.4. Challenges experienced by aquaponic stakeholders with more and less than five years of growing experience.

Chapter 3

Knowledge Levels and Training Needs of Aquaponic Stakeholders

Abstract

Aquaponics has gained considerable attention in the past several years, bringing into the fold many new hobbyists, producers, and educators. Struggles and failures of aquaponic growers call into question the viability of aquaponics as a commercial food production technology. This study assesses the importance (I) that growers place on nine core aquaponic competencies, as well as their knowledge (K) and accessibility of quality information (A) on those topics. Core competencies included system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health and disease (FHD), plant pest, disease, and nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP), and food safety (FS). Median respondent importance ratings were high, except for FRK and MFP, which hobbyists rated lowest. Similarly, knowledge of FRK and MFP were rated lower by hobbyists and educators. Quality information was generally rated as 'moderately accessible'. Ratings for each competency were summed to calculate composite scores. Composite importance scores were lowest for hobbyists and highest for producers, indicating that producers took all topics more seriously. Likewise, composite knowledge scores were lower for hobbyists than producers and educators, indicating hobbyists had lower overall knowledge levels. Composite accessibility scores were similar among groups. The top needs for knowledge and information access based on the mean weighted discrepancy score (MWDS) for all groups were in the areas of FHD and PPD, whereas FS, WC, SM,

and SD needs varied by group. Educational content in these areas would be beneficial to new and veteran aquaponic stakeholders.

Introduction

Aquaponics is an agricultural technology known to enhance water and nutrient use efficiency using a combination of recirculating aquaculture and hydroponic systems (Palm et al., 2018). System designs are flexible, with the ability to grow at different scales and adapt to local conditions. These attributes make aquaponics attractive to a variety of stakeholder groups including hobbyists/home gardeners, educators, and producers (for profit and non-profit businesses) for a variety of purposes including food production, self-sufficiency, environmental sustainability, community enhancement, and/or profit (Love et al., 2014). Interest in aquaponics has soared in recent decades (Love et al., 2014), but with any new technology the excitement of new possibilities often overshadows its current reality (Lenden and Fenn, 2003). The interdisciplinary nature of aquaponics makes for a steep learning curve causing a low success rate for many during the early stages (Hart et al., 2013; Goddek et al., 2015; Greenfeld et al., 2020b). The relative newness of aquaponics also means that few individuals have the necessary knowledge and skills required for running a successful aquaponic production facility. System failures and economic uncertainty of early adopters has instilled a heightened sense of financial risk for prospective growers and financial institutions (Greenfeld et al., 2018; König et al., 2018; Villarroel et al., 2016). The need for knowledge within the industry is great, yet to date there is no assessment that prioritizes topical areas for content development.

This study surveyed aquaponic industry participants, namely hobbyists, producers, and educators. Study goals were to 1) identify the primary motivations for stakeholder involvement in aquaponics, 2) assess their perceptions of importance, personal knowledge, and accessibility of quality information in nine core aquaponic competency areas, 3) and prioritize topic areas for educational content development. This needs assessment is relevant for teachers, Extension educators, researchers, and supporting groups seeking to develop educational products in support of the aquaponic industry.

Materials and Methods

The online survey (Qualtrics XM, Provo, UT, USA) was created to characterize respondent background and perceptions of aquaponic core competencies utilizing methods recommended by Dillman (2007) and Fowler (2009). Survey included a blend of original questions and previous industry survey questions (Love et al. 2014; Villarello et al., 2016) to collect quantitative and qualitative data using a range of question formats, including Likert and Likert-type questions (e.g. 5-point scale), binary response, as well as single and multiple selection categorical response (e.g. select from a list). The survey tool was validated externally with a trial run through the Aquaponics Association membership before approval from Auburn University's Institutional Review Board (IRB Protocol No: 19-544 EX 1912). Extension networks, professional societies, and social media groups were used to advertise and promote the survey throughout the industry, using the 'snowball' method to reach a greater audience (Browne, 2005; Baltar and Brunet, 2012; Love et al., 2014). The survey response period was open from December 10, 2019 to

June 4, 2020. The anonymous nature of data collection using social media platforms prevented an accurate response rate calculation as it was unknown how many actually saw the survey but did not complete it. Survey respondents self-selected their stakeholder group as either 1) 'hobbyists' and home gardeners, 2) for-profit and not-for-profit 'producers', or 3) 'educators' [e.g. college, kindergarten through grade 12 (K-12), Extension, etc.].

Core Competencies

Respondents rated nine core competency areas on a 5-point Likert scale based on their perceived importance (I), personal knowledge (K), and accessibility of quality information (A) on that topic. Competency areas assessed were system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health-disease (FHD), plant pest-disease-nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP) and food safety (FS). The scales were coded as 1 = *not* Important/Knowledgeable/Accessible (I/K/A), 2 = *slightly* I/K/A, 3 = *moderately* I/K/A, 4 = *very* I/K/A, and 5 = *extremely* I/K/A.

Individual respondent ratings for each competency area were summed to obtain a composite importance, knowledge, and accessibility score for each stakeholder group, providing an index of each stakeholder's overall aquaponic I, K, and A levels. To be included in the analysis the respondents had to provide a rating for each of the nine competency areas for a maximum score of 45. The composite scores give an index of overall perceptions of aquaponic competencies, with higher scores indicating greater I/K/A for all competency areas combined. The levels of the study participants can be summarized in this manner to find trends in other variables that contribute to increased understanding and self-efficacy.

Discrepancies between individual I/K/A scores were calculated to determine differences between the desired (I) and current (K or A) status. Discrepancies were calculated as their importance rating minus either their knowledge rating (I – K), importance rating minus their accessibility of quality information rating (I – A), or knowledge minus accessibility rating (K – A). Additionally, following the Borich (1980) needs assessment model, mean weighted discrepancy scores (MWDS) were calculated for each respondent in every competency area to prioritize each topic by importance. Discrepancies were weighted to emphasize their importance by multiplying them by the individual importance ratings (MWDS = [I × (I – K)] or [I × (I – A)]). This approach provides a needs assessment for training and educational materials development on each topic, where higher numbers are higher priorities.

Statistical Analysis

Data was compiled in the Qualtrics program and exported for data analysis in SPSS Statistic 26 (IBM, Armonk, NY, USA) and Excel (Microsoft 360, Redmond, WA, USA). Figures were developed using Prism 9 (GraphPad, San Diego, CA, USA) The reliability of the responses was evaluated through manual reviewing of responses and descriptive statistics for extreme outliers or illogical responses. These responses were either excluded pairwise or listwise depending on the analysis. Descriptive statistics were used to express the central tendency and spread of the data (e.g. mean ± standard deviation (SD) or standard error (SE)), median (M) and inter-quartile range (IQR)), and proportions (e.g.

percentage) were used to generalize stakeholder responses. Difference among group means were evaluated using a one-way Analysis of Variance (ANOVA) with Tukey's Post-Hoc test for pairwise comparisons among groups ($\alpha = 0.05$). Data was transformed with the natural logarithm function where appropriate to meet normality assumptions. Pearson's correlation coefficient (r) was used to measure the strength and nature of relationships between sets of variables with Bonferroni adjustment for multiple comparisons ($\alpha = 0.05/n$) to reduce the risk of Type I error. Spearman's correlation coefficient (ρ) was used as a non-parametric alternative when ordinal data was analyzed. In congruence with Evans (1996), correlations were defined as very weak ($0.0 < r/\rho < 0.19$), weak ($0.2 < r/\rho < 0.39$), moderate ($0.4 < r/\rho < 0.59$), strong ($0.6 < r/\rho < 0.79$), or very strong ($0.8 < r/\rho < 1.0$). For Likert scale questions Cronbach's alpha was calculated to validate that question response variables were loaded together appropriately. Cronbach's alpha was 0.888 for knowledge, 0.849 for importance, and 0.893 for accessibility, indicating that the Likert scale data was reliable.

Results

Demographics and Background

Out of 378 respondents, 28% were hobbyists (n = 105), 41% were producers (n = 156), and 31% were educators (n = 117). The number of respondents (n) per question varied and is noted in each table and figure. The typical respondent was 55 to 64 years of age, male, white/Caucasian, American, and employed full time, although many hobbyists and producers were retirees (Table 1). The median years of aquaponic experience was 3 to 5 years for all groups (Table 2), with 66% of respondents having less than 5 years of experience. Hobbyists were the least experienced group, with 79% having less than 5 years of experience compared to 63% of producers and 58% of educators. Eighty percent of respondents had some sort of training, with informal training being the most common overall. Out of 298 respondents, 64% had informal training, 41% had work experience, 24% had formal training, and 20% had no training at all (Table 2). The average number of training types selected (excluding non-trained respondents) was 1.3 ± 0.5 for hobbyists, which was significantly lower ($p = 0.001$) than producers (1.8 ± 0.7), but not different than educators (1.5 ± 0.7). Hobbyists (63%), producers (71%), and educators (57%) relied mostly on informal aquaponic training opportunities like workshops. Producers also indicated they had work experience (59%), while 40% of educators had formal education in aquaponics.

Overall, the number of training sources used was positively correlated with years of aquaponic experience ($\rho = 0.342$, $p < 0.001$), composite knowledge score ($\rho = 0.321$, $p < 0.001$) and development stage ($\rho = 0.172$, $p = 0.009$) (Table 3). Overall, the most common primary aquaponic interests were environmental sustainability and healthy food (Table 2). Self-sufficiency, healthy food, fish, and education were also common interests. Of the 321 respondents, 57% currently had operational aquaponic systems (Table 2).

Core Competency Perceptions

Median importance ratings for all competencies were ‘very important’ (I = 4) to ‘extremely important’ (I = 5) except for FRK and MFP (Table 4). Hobbyists and educators rated FRK as ‘moderately important’ (I = 3), while producers found it ‘very important' (I = 4). Hobbyists felt MFP was 'less important' (I = 2) than producers (I = 4) and educators (I =3).

Knowledge ratings generally ranged from 'slightly knowledgeable' (K = 2) to 'very knowledgeable' (K = 4) and varied by stakeholder group (Table 4). Producers and educators provided similar knowledge ratings across all competencies except for FRK where producers were more knowledgeable, and all groups felt least knowledgeable about MFP, with hobbyists rating it the lowest (Table 4).

Information access was generally rated as 'moderately accessible' (A = 3) (Table 4). Hobbyists rated SD and SC highest (A = 4) and MFP lowest (A = 2). Producers rated all accessibility of aquaponic information items similarly (Table 3). Educators rated accessibility highest for WC (A = 4), and all others as moderate (A = 3).

Composite Scores

Producers composite scores for importance were significantly higher than hobbyists and educators ($p \leq 0.001$), and educator importance scores were significantly higher than hobbyists ($p = 0.037$) (Table 5). Composite scores for knowledge were significantly lower for hobbyists than producers ($p < 0.001$) or educators ($p < 0.001$) (Table 5). Composite scores for access to quality information were not significantly different ($p = 0.121$) among stakeholder groups (Table 5).

Correlations

Significant correlations ($\alpha = 0.05/21 = 0.002$) were either moderate ($0.5 < r < 0.7$) or weak ($0.3 < r < 0.5$) (Evans, 1996) (Table 3). Among all groups, composite scores for knowledge were weakly positively correlated with importance composite scores (r = 0.374, $p < 0.001$), and information accessibility composite scores (r = 0.334, $p < 0.001$) (Table 3). Importance and accessibility composite scores were also weakly positively correlated (r = 0.241, $p < 0.001$). Across all groups, years of experience and composite knowledge scores were moderately positively correlated (Table 3). Years of experience was less consistently correlated with the number of training sources used and composite importance score, with correlation strength varying by stakeholder group (Table 3). Interestingly, in the hobbyist group there was a weak negative correlation between education and years of experience (Table 3). The strongest correlations existed between knowledge score and years of experience across all groups.

Discrepancy Analysis

The mean discrepancy (±SE) between the 'desired' and 'current' state (e.g. I – K, I – A, and K – A) are presented by competency area in Figures 1-3. Hobbyist and educator discrepancies between I and K were greatest for FHD, PPD, FS, which was similar to producers, with the addition of MFP (Figure 1). Discrepancies between I and A were greatest in the areas of FHD, PPD, and FS and least in FRK and MFP for hobbyists (Figure 2). Producer I – A was similar across competencies, except for FRK, which was lower (Figure 2). Educator I – A was greatest for SM and lowest for FRK and MFP (Figure 2). Discrepancies between K and A varied by user group and by competency area. Positive discrepancies indicate greater knowledge than access, whereas negative discrepancies indicated greater access than knowledge. The only consistently positive K – A was for SM, whereas FHD, PPD, and FS were consistently negative (Figure 3).

Mean Weighted Discrepancy Score (MWDS)

Based on MWDS the top needs for knowledge and information for all groups were in the areas of FHD and PPD (Table 6). In greater to lower order, hobbyists lacked knowledge in FS, WC, SD, SM and SC relative to topic importance. Producers showed need in FS, WC, SD, and MFP. Educator knowledge was particularly lacking for MFP, FS, and SD. Knowledge MWDS was significantly higher for hobbyists compared to educators for FHD ($p = 0.001$) and PPD ($p = 0.026$), but significantly lower for MFP ($p = 0.007$), Table 6.

Information access needs varied by group but were more common in the areas of FHD, PPD, SM, FS, and SD. Hobbyist information needs were greatest for FHD, PPD, FS, SM, WC, and SD. Producers had greatest information needs for SD and FHD, followed by MFP, SM, PPD, WC, FS and SC. Educator information needs were highest for SM, followed by FS, FHD, SD, and PPD. Hobbyists information access MWDS was significantly lower than producers for SD ($p = 0.011$) and MFP ($p < 0.001$), Table 6.

Discussion

Priorities and Importance

In this study, the primary interests in aquaponics revolved around environmental sustainability, healthy food, fish and plant production, and self-sufficiency. Making money and education were also important for producers and educators, respectively. This is similar to the findings of Love et al. (2014), who reported that self-sufficiency and environmental sustainability were the greatest personal priorities for all aquaponic practitioners, followed by personal and community health, climate change, and education. Whereas making money, international development, and faith-based work were the lowest priorities (Love et al., 2014). Personal priorities tend to vary across stakeholder group and location and are often skewed by personal and professional backgrounds (Hart et al., 2013; Love et al., 2014; 2015 a & b; Genello et al., 2015; Villarroel et al., 2016). In this study, the importance ratings for each competency indicate the priority level that respondents placed on them (Table 4).

The I/K/A levels of aquaponic stakeholders were not uniform across groups. Hobbyist's did not rate any core competency area as extremely important but did rate seven of the nine areas as very important (SD, SC, SM, WC, FHD, PPD, FS), FRK as moderately important (I = 3) and MFP as somewhat important (I = 2) (Table 4). Producers placed the greatest importance on all competencies (I = 4 to 5) and educators generally fell between (I = 3 to 5), with lower importance placed on FRK and MFP (I = 3) (Table 4). The positive correlation between importance, knowledge, and accessibility indicates that respondents were more willing to find and learn information if they found it important (Table 3). Hobbyists I/K/A ratings were generally the lowest for each competency. Because hobbyists are typically involved in aquaponics for fun, it is not necessary for them to become an expert in all areas of aquaponics, especially the business (e.g. FRK and MFP) and regulatory (e.g. FS) aspects. Producers generally provided the highest I/K/A ratings for each competency area. This is likely because they have invested much of their own time and capital into the success of their operation and are likely to be more diligent about seeking and gaining knowledge in each of the competency areas. Educators generally fell between hobbyists and producers in terms of their competency ratings. This is likely because they take the success of their system more seriously than hobbyists and understand the need for knowledge in all the core competency areas so they can successfully teach the core topic in their classes and demonstration units. The need to be proficient in the business and regulatory competency areas is not critical for most educators, because it does not directly affect their livelihood and other work responsibilities may take precedence. However, students would benefit from learning FRK, MFP, and FS, especially if they go on to operate commercial facilities.

The importance rating provides an upper boundary for the ‘desired state’, while knowledge ratings describe the ‘current state’ for respondents. Ratings for the accessibility of quality information provides an assessment of the ease of obtaining relevant and beneficial information. The size of discrepancies between importance ratings and knowledge or information access ratings indicated a relative need in that core competency area. The difference between knowledge and accessibility ratings (K – A) can be interpreted as whether or not information access was an impediment to stakeholder knowledge. For example, if the discrepancy is a positive number, knowledge was greater than access, indicating that information resources were not a limitation to the knowledge gained. Alternatively, if access was greater than knowledge, the discrepancy would be negative, indicating that the participants felt the information was available, but their knowledge was low. This may mean that the concept is difficult to grasp, or it is not critical to their aquaponics operation. This is an important concept to understand for those generating resources for aquaponic users. Unfortunately, the current survey design is not equipped to adequately explain this phenomenon and should be pursued in future research.

Knowledge and Experience

Knowledge is a common barrier to successful aquaponic adoption by stakeholders (Hart et al., 2013; Greenfeld et al., 2018; 2020b). The core competencies chosen for analysis in this study related to inherent risks to aquaponic newcomers, which included difficulty obtaining funding (Engle, 2015; König et al., 2018), navigating aquaculture permits and regulation (Engle and Stone, 2013), constructing and learning to operate a system to produce marketable crops (Tyson et al., 2011), complying with food safety and certification standards (Hollyer et al., 2009), as well as effectively marketing the product at a price that promotes profitability (Engle, 2015). The effort required for mastery of all aspects of aquaponics can be tremendous and the timeframe for obtaining the skills needed to succeed is relatively short.

Greenfeld et al. (2020b) analyzed the Love et al. (2014) survey data to identify knowledge levels of recent aquaponic adopters. Respondents with up to two years of aquaponic experience reported higher knowledge of each topic than those with one year or less. Over half (59%) of respondents had prior aquaponic knowledge, but 41% did not have sufficient fish or plant knowledge during their first year of operation. Similarly, in this study, there was a positive correlation between user knowledge and years of experience. This suggests that hands-on experience is necessary to develop the knowledge and skills required to be successful in aquaponics. Moreover, untrained and inexperienced growers may use troubleshooting tactics that can actually harm their system rather than getting the desired benefit (Mchunu et al., 2018). For example, certain fish species can be particularly difficult to raise, especially when one does not have a firm grasp of water chemistry and fish health. Making improper water quality modifications can actually lead to stress and disease (Pattillo, 2014). This could apply to educators who might feel more confident in their knowledge levels early in the learning process but are unaware of challenges simply because they have not yet experienced them (Cline, 2011).

In our study, median respondent knowledge levels generally fell between 'slightly knowledgeable' and 'very knowledgeable' for SC (K = 3 to 4), WC (K = 3 to 4), FHD (K = 2 to 3), PPD (K = 3), and FS (K = 3). These findings are similar to Love et al. (2014), who reported that aquaponic practitioners had high self-confidence in plumbing and water chemistry (K = 4 to 5), moderate self-confidence in fish and plant husbandry (K = 3 to 4), and low confidence in food safety and fish sale regulations (K = 2 to 4).

The relatively low percentage of respondents with operational facilities (57%) in this study may indicate a lack of hands-on experience with aquaponics within the industry. Two thirds (66%) of all respondents had < 5 years of experience compared to 89% reported by Love et al. (2014), indicating a potential increase in grower retention of 23% beyond the 5-year mark. In this study, hobbyists had the greatest turnover rate, with 79% having 5 years of experience or less compared to 63% of producers, and 58% of educators (Table 2). When considering the positive relationship between experience and knowledge, it is important to increase grower retention to improve overall industry knowledge and success. Extension and education programs and industry associations could represent key factors in recruitment and retention of new growers.

Training Access Needs

Finding skilled labor is a challenge for aquaponic producers because there are very few schools or other avenues that offer relevant training; and thus, employees are trained frequently on the job (Goddek et al., 2019; Milliken and Stander, 2019). Although education is helpful to initiate grower knowledge, hands-on experience is critical to honing skills and making informed management decisions. Years of experience in aquaponics was positively correlated with knowledge level in this study (Table 3). This is supported by Greenfeld et al. (2020b), who found that aquaponic practitioners in their second year of production reported higher self-efficacy levels than those in their first year. Hart et al. (2013) indicated physical modifications to the aquaponic system (e.g. size, plumbing, growing systems, equipment, etc.), seeking community connections and support for various aspects of running the system, developing a passion for aquaponics, seeking mentorship, and developing personal expertise through hands-on experience are all ways to overcome operational knowledge deficiencies.

Discrepancies indicate a difference between the current state and the desired state. When weighted by topic importance the MWDS allows one to prioritize certain areas for inclusion in research and educational programs (Borsch, 1980). In this study, overall priority areas for content development dealt with fish and plant production and management. Food safety (FS), WC, SD and SC were also areas of need, but varied by group (Table 6). Marketing food products was a greater need for producers and educators than hobbyists. Fish health, SD, and SM were areas of greatest need for hobbyists, producers, and educators, respectively. Cline (2011) provided MWDS analysis for aquaculture educational content standards, finding the greatest discrepancy in the area of controlling diseases and pests in aquatic environments, and fish health management, which is consistent with the high MWDS for FHD in this study. Kennel (2009) found the greatest MWDS in pre-service agricultural teachers in the areas of plant identification, effects of pesticide use, identification of common pests and diseases, and maintenance of greenhouse irrigations systems. Teachers had difficulty identifying plant pests and diseases as well as maintaining greenhouse irrigation systems both before and after instruction, indicating that these concepts may be difficult to grasp (Kennel, 2009).

Facilities

Understanding local climate effects and how they play into system design, fish/plant choices, production costs, expected sales price, and profitability are critical to success (Rakocy et al., 2004; Engle 2015; Love et al., 2015c; Goddek and Körner, 2019). Environmental control for plant production requires providing appropriate light, temperature, humidity, airflow, integrated pest management and other factors that influence plant production. Respondents understood that SD was extremely important (I = 5), and they felt they were very knowledgeable (K = 4) but felt that access to quality information on this topic was only moderate (A = 3).

Operations

Competencies used daily by all stakeholder groups included SM, WC, FHD, and PPD, which were generally rated of high importance (I = 4 to 5), but knowledge levels varied (K = 2 to 4) (Table 4). Tyson et al. (2011) suggested that operations and management factors such as optimizing the production environment (e.g. water chemistry, pH, biological filtration, temperature, and light), maximizing production outputs (e.g. fish and plants), and minimizing effluent discharge into the environment are the top sustainability challenges. Hart et al. (2013) reported top educator challenges were technical difficulties encountered while planning, building, and running the system; space, infrastructure, and administrative support, followed by restrictions associated with operating in a school setting; and finding time and labor to run and maintain the system, especially through summer breaks and holidays. Careful management of energy, labor, water and other plant and fish inputs are necessary for production efficiency and minimizing production costs (Love et al., 2015a & c). Selecting compatible, easy-to-grow, locally available fish and plant species that are disease resistant and have good market value is a challenge for growers (Bailey and Ferrarezi, 2017). Additionally, managing both subsystems to optimize health and production output can be difficult, which is a benefit of decoupled systems (Monsees et al., 2017; Yep and Zheng, 2019).

Business

There was great variability in the importance placed on FRK and MFP by the different stakeholders with producers rating them highest (I = 4 to 5) and hobbyists rating them lowest (I = 2 to 4 and I = 1 to 3, respectively) (Table 4). Producers required additional focus on FRK and MFP as they are critical to aquaponic business. Aquaponic product demand is often low and production cost is often high, discouraging investment at appropriate system scale to operate profitably (Xie and Rosentrater, 2015; Quagrainie et al., 2017), therefore production cost and markets for fish and plants should be researched before beginning system construction. Marketing requires connecting to clientele that are willing to pay a premium for aquaponic products (Short et al., 2017). Unfortunately, consumers are generally unaware of aquaponics (Zugravu et al., 2016; Short et al., 2017; Miličić et al., 2017; Greenfeld et al., 2020a) and this lack of recognition negatively affects aquaponic product price or provides no premium (Abbey, 2018; Yue et al., 2020). Consumer education could be achieved through news sources as well as at the retail store level because consumers tend to display trust and preference in these outlets (Zugravu et al., 2016; Short et al., 2017). Knowledge limitations also exist for secondary (i.e. consultants, manufacturers, suppliers, service providers) and tertiary groups (i.e. regulatory agencies, media, food retailers, consumers, animal rights groups, NGOs, general public) (Campbell et al., 2015; Zugravu et al., 2016; Short et al., 2017; Miličić et al., 2017; Greenfeld et al., 2020a & b). Education on multiple levels will be necessary to move the industry forward.

Regulations

Food safety (FS) was rated of high importance (I = 4 to 5) by all groups, but their knowledge was low (K = 2 to 3) and information access was moderate (A = 3 to 4). There are many regulatory areas that aquaponic farmers must keep up with. Not only do farmers need to be able to run the systems but they also have to operate in an environment of increasing scrutiny of agriculture practices, products, and food safety (Engle and Stone, 2013; Goddek et al., 2015). In the US, regulatory issues associated with aquaponics are broad, with multiple regulating agencies (Engle and Stone, 2013; Tomlinson, 2015). Food safety standards are stringent, requiring processing facilities that meet the Hazard Analysis and Critical Control Point (HACCP) certification and Food Safety and Modernization Act (FSMA) criteria for sanitation (Elumalai et al., 2017).

Recommendations

Recommendations for newcomers to aquaponics from the author's perspective would be to find high-quality local, regional, and/or national training opportunities to attend. Opportunities to learn and network with like-minded individuals is the goal of professional associations (e.g. Aquaponics Association, World Aquaculture Society, US Aquaculture Society, American Society for Horticultural Science, etc.), and should be pursued by newcomers, especially in the startup phase. A local or university-based aquaponic demonstration facility could provide a year-round course with internship and/or mentorship opportunities to foster encouragement, skills development, and provide troubleshooting advice. To ensure that Extension is providing top quality information, it is necessary to properly train Extension agents in aquaponics. This can be done through train-the-trainer workshops and by instituting university level curriculums in aquaponics. This would also benefit agriculture educators, who can train students in aquaponics and expand interest and workforce training opportunities at multiple levels. A one-day workshop could introduce aquaponic system choices, specifics of how to grow fish and plants, water quality, marketing, etc., but would be short on any hands-on experiences. A three-day workshop could cover the basics in more depth, mix in with hands-on experiences, and a visit to an operating aquaponics site. A seven-day workshop could provide more detail on technical aspects, add more hands-on activities, and add a section on pricing and marketing of products. Ideally, the topic areas of system cost, capital and equipment needs, water source, plant and fish production specifics, pest/disease control, watering, harvesting, processing, and marketing should be included to some degree in any length workshop. Reduced program cost and increased accessibility could be accomplished through online instructional opportunities such as webinars and periodic online distance education workshops.

Conclusion

Education of aquaponic stakeholders is necessary for the future success of the industry (Goddek et al., 2015). Given the considerable constraints facing aquaponic producers a comprehensive educational initiative is needed (Greenfeld et al., 2018; Konig et al., 2018; Palm et al., 2018). More Extension agents and educators should be trained in aquaponics to provide opportunities and informational resources in a variety of individual and group formats for participants to learn and network. Core competency areas evaluated in this study should be covered during trainings to varying degrees based on the target audience, their needs, and their knowledge level. Delivery methods such as lectures would impart knowledge, hands-on activities would provide confidence, site visits would give proof, and value stream exercises would give assurances that aquaponic enterprises can be viable. Each State's Land Grant University system should be available to help newcomers and train students in aquaponics to fill the roles of skilled workers, entrepreneurs, consultants, manufacturers, suppliers, teachers, researchers, and Extension agents.

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Table 3.1. Demographic identifiers of hobbyists, producers, and educators responding to the survey.

Demographic Category		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Stakeholder Group		105	25	156	37	117	28
Age Group	18-24	1	2	1	1	0	0
	25-34	5	7	12	15	5	9
	35-44	10	15	15	19	11	19
	45-54	15	22	15	19	14	24
	55-64	20	29	25	32	20	34
	65-74	11	16	10	13	7	12
	>75	6	9	1	1	1	2
	Total	68	100	79	100	58	100
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	65	100	75	100	59	100
Education	≤ High school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	66	100	77	100	61	100
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	66	100	74	100	57	100
Ethnicity	Asian	4	5	4	5	3	5
	Black	1	2	7	9	6	10
	Hispanic	1	2	0	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	59	78	38	63
	Other	1	2	0	0	5	8
	Undisclosed	5	7	6	8	3	5
	Total	68	100	76	100	60	100
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	68	100	71	100	59	100

Table 3.2. Experience, training, interests, and development stage of aquaponic stakeholders.

		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Years of Aquaponic Experience	< 1 year	25	24	29	19	16	14
	1-2 years	22	21	31	20	21	18
	3-5 years	35	34	38	24	30	26
	6-10 years	18	18	38	24	31	26
	11-20 years	3	3	15	10	10	8
	>20 years	0	0	4	3	9	8
	Total	103	100	155	100	117	100
Training Source	Informal Training	54	63	89	71	49	57
	Work Experience	16	19	74	59	31	36
	Formal Training	8	9	30	24	34	40
	No Training	30	35	19	15	12	14
	N*	86		126		86	
Primary Interest in Aquaponics	Sustainability	55	53	106	68	62	53
	Healthy Food	65	63	92	59	44	38
	Fish	49	47	67	43	58	50
	Plants	47	45	64	41	42	36
	Self Sufficiency	62	60	66	43	23	20
	Education	16	15	31	20	78	67
	Making Money	11	11	60	39	10	9
	Other	10	10	21	14	9	8
	Work Requirement	3	3	10	6	20	17
	N	104		155		117	
Development Stage	Researching	16	17	12	9	20	22
	Planning	17	18	38	28	14	16
	Constructed	6	6	8	6	7	8
	Operational	56	59	79	58	48	54
	Total	95	100	137	100	89	100

* N is the number of respondents that responded to the question when there was more than one selection option.

Table 3.3. Pearson correlations between experience, training, information resource utilization, and composite scores of knowledge, importance, information accessibility, education, and development stage for survey participants.

Hobbyist		1	2	3	4	5	6
1	Years of Experience	--					
2	Number of Training Sources	**.415****	--				
3	Knowledge Score	**.545****	**.404****	--			
4	Importance Score	.103	.054	**.321****	--		
5	Accessibility Score	.213	.052	**.414****	.151	--	
6	Education Level	**-.277***	.042	-.198	-.036	-.201	--
7	Development Stage	**.378****	.016	**.230***	**-.281***	.082	**-.279***

Producer		1	2	3	4	5	6
1	Years of Experience	--					
2	Number of Training Sources	.139	--				
3	Knowledge Score	**.436****	.121	--			
4	Importance Score	.010	-.092	**.250***	--		
5	Accessibility Score	.127	.019	**.312****	**.278****	--	
6	Education Level	.128	.031	.152	.067	-.040	--
7	Development Stage	**.467****	.105	**.306****	-.124	-.065	-.110

Educator		1	2	3	4	5	6
1	Years of Experience	--					
2	Number of Training Sources	**.396****	--				
3	Knowledge Score	**.449****	.189	--			
4	Importance Score	.184	.093	**.259***	--		
5	Accessibility Score	.054	.125	.165	.146	--	
6	Education Level	.182	.159	.105	.112	.078	--
7	Development Stage	**.282***	**.311***	.022	.009	.185	.049

***$p \leq 0.05$, **$p \leq 0.002$;** Bonferroni adjustment for multiple correlations to minimize risk of Type I error. ($\alpha = 0.05/21 = 0.0024$).

Table 3.4. Median and interquartile range (IQR) of importance, knowledge, and accessibility of quality information ratings for aquaponic hobbyists, producers, and educators.

	Hobbyist		Producer		Educator	
[*]Importance Rating (I)	Median	(IQR)	Median	(IQR)	Median	(IQR)
[†]SD	4	(4-5)	5	(4-5)	4	(4-5)
SC	4	(3-5)	4	(4-5)	4	(4-5)
SM	4	(4-5)	4	(4-5)	5	(4-5)
WC	4	(4-5)	5	(4-5)	5	(4-5)
FHD	4	(4-5)	5	(4-5)	5	(4-5)
PPD	4	(4-5)	5	(4-5)	4	(4-5)
FRK	3	(2-4)	4	(4-5)	3	(2-4)
MFP	2	(1-3)	4	(4-5)	3	(3-4)
FS	4	(3-5)	5	(4-5)	4	(4-5)
Knowledge Rating (K)	Median	(IQR)	Median	(IQR)	Median	(IQR)
SD	3	(3-4)	4	(3-4)	4	(3-4)
SC	3	(3-4)	4	(3-4)	4	(3-4)
SM	3	(3-4)	4	(3-4)	4	(3-4)
WC	3	(2-4)	4	(3-4)	4	(3-5)
FHD	2	(2-3)	3	(2-4)	3	(2-4)
PPD	3	(2-3)	3	(3-4)	3	(2-4)
FRK	3	(2-3)	4	(3-4)	3	(2-4)
MFP	2	(1-2)	3	(3-4)	3	(2-3)
FS	3	(2-3)	3	(2-3)	3	(2-4)
Accessibility Rating (A)	Median	(IQR)	Median	(IQR)	Median	(IQR)
SD	4	(3-4)	3	(3-4)	3	(3-4)
SC	4	(3-4)	3	(2-4)	3	(3-4)
SM	3	(3-4)	3	(3-4)	3	(3-4)
WC	3	(3-4)	3	(3-4)	4	(3-4)
FHD	3	(2-4)	3	(3-4)	3	(3-4)
PPD	3	(2-4)	3	(3-4)	3	(3-4)
FRK	3	(2-4)	3	(3-4)	3	(2-4)
MFP	2	(2-3)	3	(2-4)	3	(2-4)
FS	3	(2-4)	3	(3-4)	3	(3-4)

[*] Ratings based on a Likert scale where 1 = *not* Important/ Knowledgeable/ Accessible (I/K/A), 2 = *slightly* I/K/A, 3 = *moderately* I/K/A, 4 = *very* I/K/A, and 5 = *extremely* I/K/A.

[†] System Design (SD), System Construction (SC), System Maintenance (SM), Water Chemistry (WC), Fish Health & Disease (FHD), Plant Pest, Disease, and Nutrient Deficiencies (PPD), Financial Record Keeping (FRK), Marketing Food Products (MFP), Food Safety (FS)

Table 3.5. Composite scores of aquaponic knowledge, importance, and access to quality information for hobbyist, producer, and educator stakeholders.

	Composite Score								
	Hobbyist			Producer			Educator		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Knowledge	25.3 ***b***‡	6.3	93	30.8 ***a***	6.5	139	29.3 ***a***	7.3	97
Importance	34.3 ***c***	5.6	91	39.2 ***a***	5.4	139	36.5 ***b***	5.8	95
Accessibility	27.1	8.0	75	29.3	6.3	125	29.4	6.0	74

‡ Comparisons should be made by row between groups. Letters denote statistically significant differences ($p < 0.05$) between stakeholder groups. Only significant differences are noted

Table 3.6. Mean weighted discrepancy score for differences between aquaponic topic importance and topic knowledge or access to information.

	Mean Weighted Discrepancy Score*					
	Importance - Knowledge			Importance - Info Access		
Topic Area†	Hobbyist	Producer	Educator	Hobbyist	Producer	Educator
FHD	8.00 ***a***‡	6.64 ***ab***	5.41 ***b***	6.01	6.12	4.29
PPD	8.11 ***a***	6.38 ***ab***	4.84 ***b***	6.23	5.55	4.05
FS	6.43	5.21	4.83	5.43	5.10	4.64
SM	4.72	3.09	3.80	4.93	5.59	5.48
SD	5.00	4.05	4.05	3.87 ***y***‡	6.15 ***z***	4.10 ***yz***
WC	5.22	4.56	3.10	4.83	5.13	3.55
MFP	2.72 ***b***	3.39 ***ab***	5.24 ***a***	1.74 ***y***	5.99 ***z***	3.11 ***y***
SC	3.90	3.10	3.14	3.31	5.10	3.34
FRK	1.12	2.25	2.29	1.04	3.21	2.36

* MWDS = [Importance × (Importance – Knowledge or Access)]

‡ Comparisons should be made by row between groups. Letters denote statistically significant differences ($p < 0.05$) between stakeholder groups. Only significant values are reported.

† Topic areas appear in descending order based on average MWDS for knowledge and access.
System Design (SD), System Construction (SC), System Maintenance (SM), Water Chemistry (WC), Fish Health & Disease (FHD), Plant Pest, Disease, and Nutrient Deficiencies (PPD), Financial Record Keeping (FRK), Marketing Food Products (MFP), Food Safety (FS)

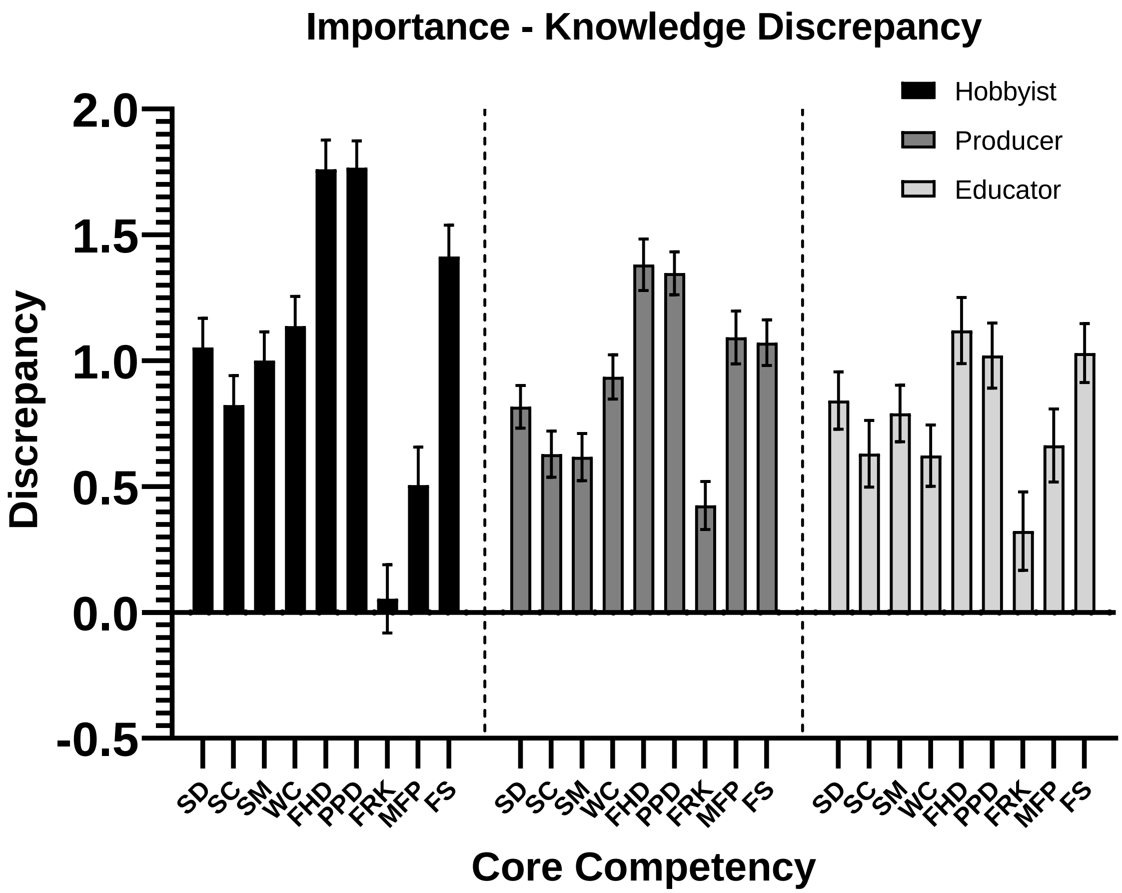

Figure 3.1. Mean discrepancy (±SE) for importance rating minus knowledge rating on a 5-point Likert scale for nine core competency areas for aquaponic hobbyists, producers, and educators. Core competencies included system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health and disease (FHD), plant pest, disease, and nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP), and food safety (FS).

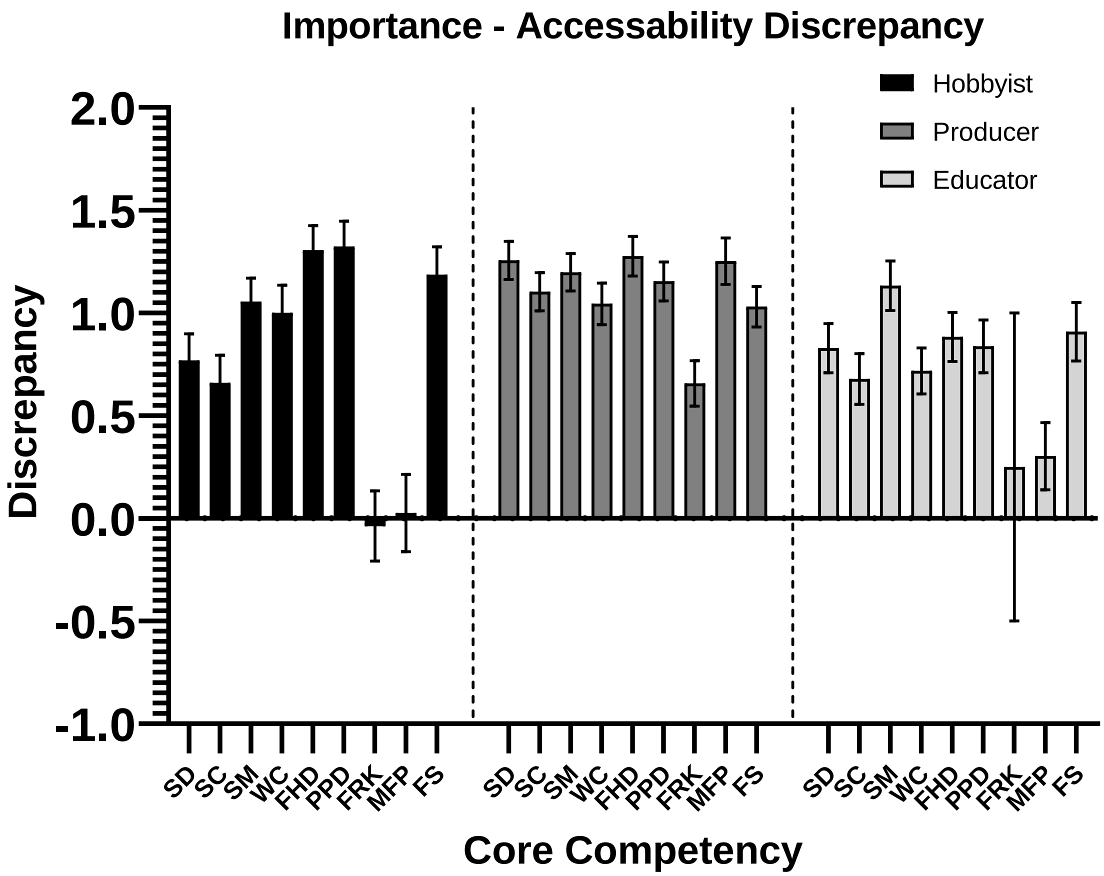

Figure 3.2. Mean discrepancy (±SE) for importance rating minus accessibility of quality information rating on a 5-point Likert scale for nine core competency areas for aquaponic hobbyists, producers, and educators. Core competencies included system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health and disease (FHD), plant pest, disease, and nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP), and food safety (FS).

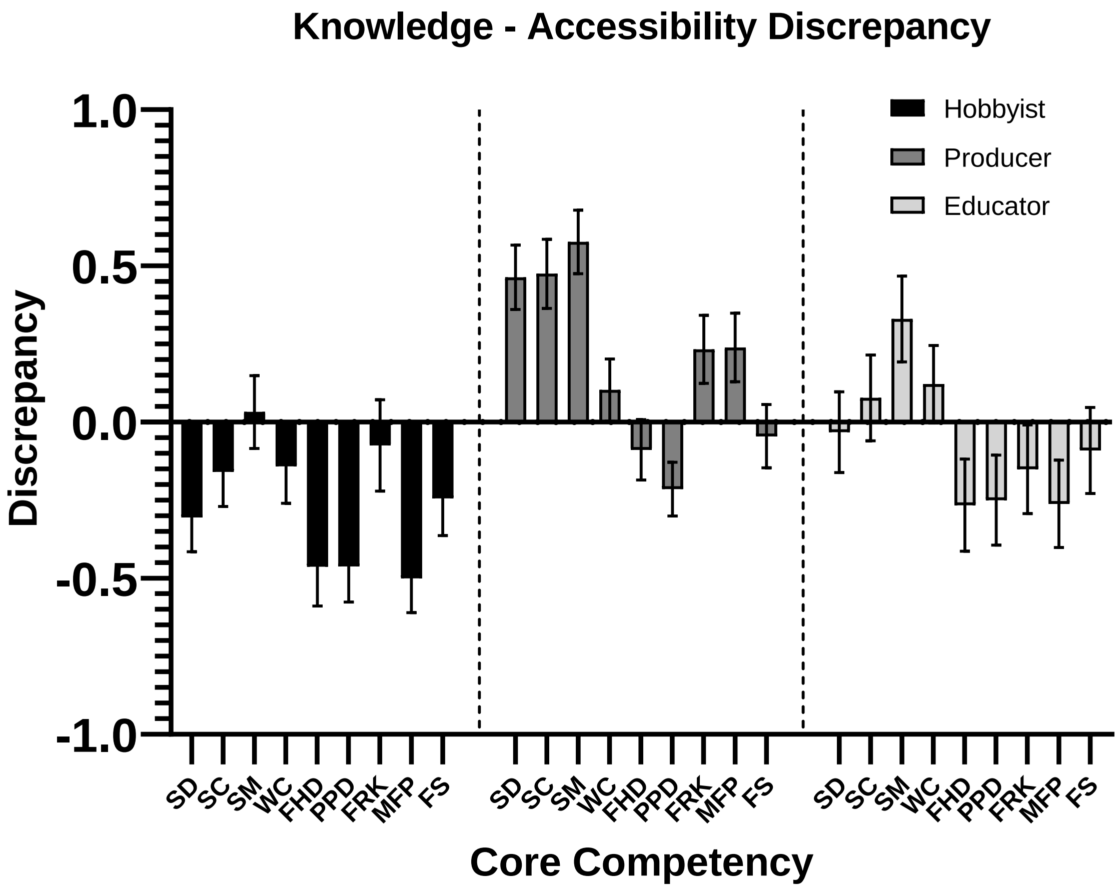

Figure 3.3. Mean discrepancy (±SE) for knowledge rating minus accessibility of quality information rating on a 5-point Likert scale for nine core competency areas for aquaponic hobbyists, producers, and educators. Core competencies included system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health and disease (FHD), plant pest, disease, and nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP), and food safety (FS).

Chapter 4

Information Accessibility and Resource Usage by Aquaponic Stakeholders

Abstract

Aquaponics has gained considerable attention in the past several years, bringing many new stakeholders into the fold. As with any new industry there are unknowns and misinformation presented from a variety of sources. It is critical to provide high quality information on appropriate topics in proper formats to promote success within the aquaponics industry. This study assesses usage of various informational resource outlets and accessibility of quality information in nine topic areas by different stakeholder groups. Quality information was perceived as 'moderately accessible' in general, although this varied by stakeholder group and by topic. Information on marketing food products and financial record keeping generally had the lowest accessibility ratings overall. Hobbyists rated system design and system construction accessibility highest, producer ratings were similar across topics, and educators rated water chemistry highest. Results indicated the most commonly utilized information sources overall were internet and videos, books and library, and classes and workshops. The most commonly desired information resources overall were other aquaponic growers, extension agents, classes/workshops, extension publications, and manufacturers/suppliers. The three most unused resources across all groups were friends and family, consultants, and social media. This study provides a guide for prioritizing efforts to inform and support aquaponic growers from novice to advanced. Information gathered can serve as a guide and needs assessment for content providers like academics, consultants, public agencies,

and non-government organizations to create and distribute science-based resources, to support continued development of the industry.

Introduction

Aquaponics is a growing field of agriculture that integrates fish and plant culture for food production, self-sufficiency, environmental sustainability, community enhancement, and/or profit (Love et al., 2014). System designs can be flexible, scalable, and adaptable to local conditions, making them attractive to a variety of stakeholder groups with vested interests in the success of aquaponics but in different ways (Villarroel et al., 2016). The aquaponics industry is currently in a growth phase, with interest levels soaring in recent decades and new production systems are being developed around the world (Love et al., 2014). But with any new technology the excitement of new possibilities often overshadows its current reality (Lenden and Fenn, 2003; Junge et al., 2017; Turnsek et al., 2020) and economic uncertainty surrounding aquaponics has made for some costly failures for early adopters (König et al., 2018; Greenfeld et al., 2018).

The interdisciplinary nature of aquaponics makes for a steep learning curve and potentiates a low success rate especially during the early stages (Hart et al., 2013; Goddek et al., 2015; Greenfeld et al., 2020a). The relative newness of aquaponics also means that few individuals have the necessary knowledge and skills required for running a successful aquaponic production facility. Many aquaponic stakeholders pursue aquaponics as an expansion of their current interests in aquaculture or horticulture, as a community development project, or as a retirement endeavor (Villarroel et al., 2016).

Lack of access to reliable information in critical areas can cause growers to make costly mistakes or waste significant time learning production techniques through trial and error. Newcomers may feel a naive sense of self-confidence in managing their system while their actual troubleshooting skills may be inadequate (Mchunu et al., 2018). This is likely related to the abundance of internet-searchable reference materials available online, which are of questionable quality and credibility (Turnsek et al., 2020). Compared to other areas of agriculture, the number and ratio of internet searchable resources that come from non-peer-reviewed sources compared to peer-reviewed sources (i.e. hype ratio) is quite high for aquaponics (Linden and Fenn, 2003; Junge et al., 2017). At the time of this publication the hype ratio (google search results : google scholar search results) for "aquaponics" is 967:1 compared to "hydroponics" (859:1), "aquaculture" (13:1), "horticulture" (37:1), "sustainable agriculture" (162:1), and "agriculture" (257:1).

This lack of credible educational resources and plethora of system scales and styles has contributed to user failures because of misinformation about system design and management. The cumulative effect of these failures is a distrust amongst growers, investors, and lending agencies resulting in the stagnation of the aquaponics industry (Turnsek et al., 2020). Regardless, the aquaponics industry continues to attract new growers, supporters, and regulatory attention. With relatively few training opportunities in aquaponics it is important to provide relevant, timely, and credible educational resources to improve grower success (Genello et al., 2015; Greenfeld et al., 2018). It is the role of educators, researchers, and extension professionals to support sustainable aquaponics and industry growth.

This study surveyed aquaponic industry participants, namely hobbyists, producers and educators. Study goals were to 1) evaluate their perceived accessibility of quality information in nine core competency areas, 2) evaluate their usage of various informational resources, and 3) provide recommendations for resource development by topic, audience, and resource type. A needs assessment such as this is relevant for teachers, extension educators, researchers, and supporting groups seeking to develop useful and easily accessible publications, videos, workshops, and other educational products in support of the aquaponic industry.

Materials and Methods

The survey tool was developed as an amalgam of previous industry surveys (Love et al. 2014; Villarello et al., 2016) and researcher-developed questions, which were validated for clarity and efficacy of data collection through a test deployment within the Aquaponics Association membership. The final survey tool (Appendix A) was designed using concepts recommended by Dillman (2007) and Fowler (2009) for online delivery (Qualtrics XM, Provo, UT, USA) with approval Auburn University's Institutional Review Board (IRB Protocol No: 19-544 EX 1912). Survey participants were solicited from social media, extension contacts, and professional associations with a focus on aquaponics from December 10, 2019 to June 4, 2020. The 'snowball' advertising method was used to expand the audience captured in the survey results, but this method prevented the calculation of a reliable response rate (Browne, 2005; Baltar and Brunet, 2012; Love et al., 2014).

Stakeholder Background

Information was collected about the respondent demographic information, stakeholder group, training experience, personal interests/motivations in aquaponics, and current development stage. Training experiences included informal (e.g. classes and workshops), work experience (e.g. on-farm training), formal (e.g. college or university), or no training. Personal interest(s) were selected from environmental sustainability, healthy food, fish, plants, self-sufficiency, education/teaching, making money, work requirement, or other. Current development stages were researching and gathering information (researching), planning and design (planning), facility constructed (constructed), or currently in operation (operational).

Core Competencies

Respondents rated nine core competency areas on a 5-point Likert scale regarding the perceived accessibility of quality information (A) on that topic. Competency areas assessed were system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health-disease (FHD), plant pest-disease-nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP) and food safety (FS). The scales were coded as 1 = *not*, 2 = *slightly*, 3 = *moderately*, 4 = *very*, and 5 = *extremely* accessible. The composite accessibility score was calculated as the sum of ‘A’ ratings for those that rated each competency area.

Informational Resource Usage

Survey respondents were presented with a list of informational resources and asked to sort them into one of three categories: ‘currently use’, ‘want to use’ (e.g. desired), and ‘do not use’ (e.g. unused). Each information source could only be sorted into one category, and therefore were mutually exclusive. The list of information sources was a) peer-reviewed scientific journals, b) extension agents, c) extension publications, d) internet and videos, e) social media, f) friends and family, g) books or library, h) classes or workshops, i) consultants, j) other aquaponic growers (i.e. hobbyists, producers, or educators), and k) manufacturers and suppliers.

Statistical Analysis

Survey response data was compiled in Qualtrics and exported for data analysis in SPSS Statistic 26 (IBM, Armonk, NY, USA) and Excel (Microsoft 360, Redmond, WA, USA). Data was reviewed manually to detect extreme outliers or illogical responses, which were excluded pairwise depending on the analysis. Data characteristics were generalized using mean ± standard deviation (SD), median (M) and inter-quartile range (IQR), and proportions (e.g. percentage). One-way Analysis of Variance (ANOVA) with Tukey's Post-Hoc test for pairwise comparisons among groups ($\alpha = 0.05$) was used to detect differences between group means. Where necessary, data was transformed with the natural logarithm function to meet normality assumptions. Ordinal data was analyzed using the nonparametric Spearman's correlation (ρ) to measure the strength (Evans, 1996) and nature of relationships between sets of variables with Bonferroni adjustment for multiple comparisons ($\alpha = 0.05/n$) to reduce the risk of Type I error. Cronbach's alpha (0.893) was calculated for Likert scaled accessibility data indicating the responses loaded in the model together appropriately and were reliable.

Results

Demographics and Background

Out of 378 respondents, 28% were hobbyists (n = 105), 41% were producers (n = 156), and 31% were educators (n = 117). The typical respondent was 55 to 64 years of age, male, white/Caucasian, American, and employed full time, although many hobbyists and producers were retirees (Table 1). The median response to the years of aquaponic experience question was 3 to 5 years for hobbyists, and 3 to 10 years for producers and educators (Table 2). Eighty percent of respondents had some sort of training, with informal training being the most common overall. Out of 298 respondents, 64% had informal training, 41% had work experience, 24% had formal training, and 20% had no training at all (Table 2). The average number of training types selected (excluding non-trained respondents) was 1.3 ± 0.5 for hobbyists, which was significantly lower ($p = 0.001$) than producers (1.8 ± 0.7), but not different than educators (1.5 ± 0.7). Overall, the number of training sources used was weakly positively correlated with years of aquaponic experience ($\rho = 0.342$, $p < 0.001$).

Overall, the most commonly selected primary interests were environmental sustainability and healthy food (Table 2). Self-sufficiency, healthy food, fish, and education were also common interests. Relatively few respondents selected making money or work requirement (i.e. learned specifically for their job) as their primary interest. Top interests for hobbyists were healthy food, self-sufficiency, and environmental sustainability. Primary interests for producers were environmental sustainability and healthy food, with making money being a greater interest for producers than other groups. Educators were primarily interested in aquaponics for education and teaching, followed by environmental sustainability and fish.

Of the 321 respondents to the question regarding their operation’s developmental stage, 57%, 21%, 15%, and 7% were in the operational, planning, researching, and construction phases, respectively (Table 2). Overall development stage was significantly correlated with the number of years of experience ($\rho = 0.370$, $p < 0.001$), number of information sources used ($\rho = 0.123$, $p = 0.041$), and number of training sources used ($\rho = 0.172$, $p = 0.009$). The strength of these correlations varies by stakeholder group (Table 4).

Core Competency Information Accessibility

The median information accessibility (A) rating was generally 'moderately accessible' (A = 3) (Table 3). Hobbyists rated SD and SC highest (A = 4) and MFP lowest (A = 2). Producers rated all accessibility of aquaponic information items similarly. Educators rated accessibility highest for WC (A = 4), and all others as moderate (A = 3). Composite accessibility scores were not significantly different among stakeholder groups ($p > 0.121$), with means ranging from 27.1 to 29.4 out of a potential score of 45. Overall, composite accessibility score was very weakly correlated (Evans, 1996)) with years of experience ($\rho = 0.173$, $p = 0.002$) and number of information resources used ($\rho = 0.148$, $p = 0.015$); however, this correlation was not detected by stakeholder group (Table 4).

Information Resource Usage

Currently used resources were sorted into the "I use this resource" category by respondents. The most commonly used information sources overall were internet and videos (87%), books and library (66%), and classes and workshops (57%) (Table 5). The average number of information sources used per respondent was significantly lower ($p < 0.001$) for hobbyists (4.4 ± 1.9) than producers (5.4 ± 2.1) and educators (5.5 ± 2.2). Overall, the number of information sources was significantly and positively correlated with years of aquaponic experience (r = 0.289, $p < 0.001$), number of training sources used (r = 0.347, $p < 0.001$) (Table 4). Table 6 provides a list of benefits and drawbacks for each of the information resource categories.

Desired resources were sorted into the “I want to use this resource” category by respondents. These resources were not currently utilized, due to lack of awareness or access, but valued by the respondent (Table 5). The most commonly desired information resources overall were other aquaponic growers (40%), followed by extension agents (38%), classes/workshops (37%), extension publications (36%), and manufacturers/suppliers (34%). Classes and workshops as well as manufacturers / suppliers were desired by hobbyists. Extension agents and publications were preferred by producers. Peer-reviewed journals were desired by hobbyists and producers, but currently in use by educators. Consultants were desired more commonly by hobbyists (32%) and educators (30%) than by producers (23%). The average number of desired information sources was 3.0 ± 1.5 per hobbyist, 2.7 ± 1.3 per producer, and 2.6 ± 1.2 per educator, which were not significantly different ($p > 0.05$) among groups.

Unused resources were those sorted into the “I do not use this resource” category by respondents (Table 5). The top three unused resources across all groups were friends and family, consultants, and social media. The average number of unused information sources was 3.0 ± 1.3 per hobbyist, 2.7 ± 1.4 per producer, and 2.7 ± 1.2 per educator, which were not significantly different ($p > 0.05$) between groups.

Discussion

Information Accessibility

The most deficient competency area for information accessibility across all groups was marketing (MFP). Financial record keeping (FRK) accessibility was rated low by hobbyists and educators. Hobbyists also rated access of to fish health (FHD), plant pests (PPD), and food safety (FS) low. Producers rated system construction (SC) information access low also. These topics should be prioritized for information resource development and presented appropriately for each stakeholder group. However, none of the topic areas stood out as overwhelmingly accessible, indicating that stakeholders could benefit from informational resources on each topic.

Information Resource Usage

All stakeholders used multiple aquaponic information sources, with the most commonly used information source across all groups being internet and videos, books and library, and classes and workshops. The common theme among these resources is comprehensive coverage of topics and relevance for specific needs (Table 6). Although the internet is the most used information resource, there are concerns over the use of web-based information because of the potential for inaccurate or biased information (Flanagin and Metzger, 2000). However, evidence suggests that information consumers find internet resources to be equally credible as television, radio, or magazines (Flanagin and Metzger, 2000). Internet video accessibility, quality, shareability on social media, and entertainment value are likely the greatest contributing factors for their use (Yang, 2007). Credible information providers like universities should focus on delivering content with the end user in mind. The perceived credibility of information resources is highly related to personal relevance and stylistic quality (e.g. language and grammar), while presenter/source and media type are less important (Yang, 2007). Nagy (2018) found that perceived video content usefulness, user attitude toward videos, and internet self-efficacy directly impacted internet video usage. Lock and Seele (2017) suggested that perceived credibility is a composite of factors relating to truth, sincerity, appropriateness, and understandability. Further, internet resources are judged initially by appearance/presentation, usability/interface design, and organization of information, then by source and content message before gaining user acceptance (Wathen and Burkell, 2002). Although many internet users may research content on social media, they are likely to seek endorsements from friends or family before following through with a purchase (Cooley and Parks-Yancy, 2019). This 'ground truthing' is a means of triangulating the validity of information. Books and peer-reviewed scientific literature should be among the most credible sources because of the rigorous review process. Peer-reviewed information like books, scientific journal articles, or extension publications are also valued by respondents. Workshops are highly desired because they provide hands-on experiences, networking opportunities and can address participant questions directly.

There was some variability in resource use by stakeholder group. Hobbyists relied more on social media, whereas producers preferred other growers, and educators preferred peer-reviewed journal articles. Common themes in these resources were networking and interaction with social media and other growers (Table 6). Non-academic stakeholders may not have access to peer-reviewed literature, making resource utilization an access limitation. Further, the language used in scientific publications is often difficult to understand for the general public, requiring synopsis with broad audience appeal in extension publications or trade articles. According to Genello et al. (2015), information sources used by educators included internet websites, followed by other growers, printed resources, university or extension, and seminars or workshops. Villarroel et al. (2016) reported that information resources used by aquaponic growers were primarily university, online, or print, followed by workshops, with very few seeking information from government agencies. As the industry grows and government awareness and regulation increase for aquaponic practitioners, the need for quality information to dispel myths also increases.

Knowledge limitations also exist for secondary (i.e. consultants, manufacturers, suppliers, service providers) and tertiary groups (i.e. regulatory agencies, media, food retailers, consumers, animal rights groups, NGOs, general public) (Campbell et al., 2015; Zugravu et al., 2016; Short et al., 2017; Miličić et al., 2017; Greenfeld et al., 2020a & b). Lack of awareness can negatively affect consumer willingness to pay more for safe, sustainable, and locally produced aquaponic products (Abbey, 2018; Yue et al., 2020). Consumer education could be achieved through news sources as well as at the retail store level because consumers tend to display trust and preference in these outlets (Zugravu et al., 2016; Short et al., 2017). Also, as US granting agencies become more aware of aquaponics and its positive potential, research funding is becoming more available.

The most desired resources were other growers, extension agents, and classes/workshops. While other farmers and extension agents were highly desired resources their less frequent use was likely an accessibility issue. Other farmers are likely to have the highest credibility because their experiences are directly relatable. Extension agents provide free information and feedback, but there are relatively few trained extension professionals in aquaponics. Many of the current class/workshop training opportunities are not associated with accredited university programs, although some do exist.

The most unused resources by survey respondents included friends/family, consultants, and social media. The lack of use is likely due to the perceived lower quality and rigor of the information, and in the case of consultants, cost. Aquaponic information resources continue to increase, produced both by researchers and enthusiasts. Misinformation on best practices on the internet provided by so-called ‘experts’ promising high return on investment and minimal work has led to failures for some start-up aquaponic businesses (Turnsek et al., 2020). As the rate of scientific research publications increases relative to other non-scientific resources, the “hype ratio” decreases (Junge et al., 2017). There is a need for free, credible information on aquaponics to be widely available and easily accessible. Synthesized scientific information, like extension or trade articles, may be more useful to most stakeholders.

Recommendations

It is critical to provide high quality information on appropriate topics in proper formats to promote success within the aquaponics industry. Programs to help aquaponic newcomers, especially in the startup phase could be very helpful. Informal education opportunities such as workshops, seminars, field days, site visits, webinars, and internet videos are highly valued across groups. Internet resources (e.g. videos, webinars, websites, and online publications) are far and away the most used sources of information. The quality and rigor of these resources should be improved to ensure accurate information is reaching intended audiences. Major factors impacting information resource use include accessibility, ease of use, and appropriateness to the project (Majid and Kanagasabai, 2007). With the prevalent use of the internet and smart devices, the trend is towards short snippets of information rather than in-depth instructional content (Cheng et al., 2013). However, when stakeholders really need to dig into the details, they tend to triangulate the validity of information with trusted sources like books, peer-reviewed literature, research-based extension resources, and experienced farmers (Sakib et al., 2015; Cooley and Parks-Yancy, 2019).

Sources of credible information (e.g. universities, etc.) should focus on delivering content through these avenues – with emphasis on appearance, presentation, usability, etc. The desire for other growers as a resource could be facilitated through social media and professional associations, as well as educational programs like classes/workshops. Although the credibility of social media can be questionable users tend to trust the content if it comes from a reputable source. Integrating more credible information can be done through webinars and online classes sponsored by a credible resource such as Extension. Connections with social and professional aquaponic groups could provide a support network for new growers when they become discouraged due to initial learning curve hindrances. Such associations could be influential in public education and affect government policy. Extension agents could be directly involved with each of these educational platforms.

Training and demonstration facilities in conjunction with long-term education programs at the high school or university level could fill the critical needs for skilled labor in the aquaponics industry. Extension specialists are great sources of top-quality information for farmers, unfortunately there are few trained in aquaculture and aquaponics (Swann and Morris, 2001). Train-the-trainer workshops would be a great way to increase the number of teachers and extension agents with an aquaponic background. Workshops may vary in content, format, and cost by their duration, but a combination of technical knowledge and hands-on experience should be targeted. The competencies evaluated in this study would be a good starting point for content development, but each program should be catered to the needs of the participants. Online alternatives like webinars and distance education classes can be employed to reduce program cost and increase access and participation.

Conclusion

Education of aquaponic stakeholders, streamlining and standardization of practices, and development of comprehensive guidelines is necessary for the future success of the industry. The initial learning curve for aquaponics is steep and training opportunities to shorten the learning timeline are needed. Core competency areas evaluated in this study should be covered during trainings to varying degrees based on the target audience and their knowledge level. There are many options for informational resources including digital, print, interactive, hands-on, and interpersonal formats, but matching this format to stakeholder needs and abilities is critical. Credible information, presented in the wrong format, may not be used by the targeted end user. Initial information delivery could focus on capturing stakeholder’s attention with short videos, then directing users to longer, more in-depth training videos. In-depth training methods could include lectures, hands-on activities, site visits, and value stream exercises to confer knowledge, confidence, perspective, and assurance that aquaponic enterprises can be viable. Additionally, more extension agents and educators should be trained in aquaponics to strengthen the aquaponic network throughout the US and world.

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Table 4.1. Demographic identifiers of hobbyists, producers, and educators that responded to the survey.

Demographic Category		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Stakeholder Group		105	25	156	37	117	28
Age Group	18-24	1	2	1	1	0	0
	25-34	5	7	12	15	5	9
	35-44	10	15	15	19	11	19
	45-54	15	22	15	19	14	24
	55-64	20	29	25	32	20	34
	65-74	11	16	10	13	7	12
	>75	6	9	1	1	1	2
	Total	68	100	79	100	58	100
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	65	100	75	100	59	100
Education	≤ High school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	66	100	77	100	61	100
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	66	100	74	100	57	100
Ethnicity	Asian	4	5	4	5	3	5
	Black	1	2	7	9	6	10
	Hispanic	1	2	0	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	59	78	38	63
	Other	1	2	0	0	5	8
	Undisclosed	5	7	6	8	3	5
	Total	68	100	76	100	60	100
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	68	100	71	100	59	100

Table 4.2. Experience, training, interests, and development stage of aquaponic stakeholders.

		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Years of Aquaponic Experience	< 1 year	25	24	29	19	16	14
	1-2 years	22	21	31	20	21	18
	3-5 years	35	34	38	24	30	26
	6-10 years	18	18	38	24	31	26
	11-20 years	3	3	15	10	10	8
	>20 years	0	0	4	3	9	8
	Total	103	100	155	100	117	100
Training Source	Informal Training	54	63	89	71	49	57
	Work Experience	16	19	74	59	31	36
	Formal Training	8	9	30	24	34	40
	No Training	30	35	19	15	12	14
	N*	86		126		86	
Primary Interest in Aquaponics	Sustainability	55	53	106	68	62	53
	Healthy Food	65	63	92	59	44	38
	Fish	49	47	67	43	58	50
	Plants	47	45	64	41	42	36
	Self Sufficiency	62	60	66	43	23	20
	Education	16	15	31	20	78	67
	Making Money	11	11	60	39	10	9
	Other	10	10	21	14	9	8
	Work Requirement	3	3	10	6	20	17
	N	104		155		117	
Development Stage	Researching	16	17	12	9	20	22
	Planning	17	18	38	28	14	16
	Constructed	6	6	8	6	7	8
	Operational	56	59	79	58	48	54
	Total	95	100	137	100	89	100

* N is the number of respondents that responded to the question when there was more than one selection option.

Table 4.3. Median and interquartile range (IQR) of accessibility of quality information ratings for aquaponic hobbyists, producers, and educators.

	Hobbyist		Producer		Educator	
***Accessibility Rating (A)**	Median	(IQR)	Median	(IQR)	Median	(IQR)
†SD	4	(3-4)	3	(3-4)	3	(3-4)
SC	4	(3-4)	3	(2-4)	3	(3-4)
SM	3	(3-4)	3	(3-4)	3	(3-4)
WC	3	(3-4)	3	(3-4)	4	(3-4)
FHD	3	(2-4)	3	(3-4)	3	(3-4)
PPD	3	(2-4)	3	(3-4)	3	(3-4)
FRK	3	(2-4)	3	(3-4)	3	(2-4)
MFP	2	(2-3)	3	(2-4)	3	(2-4)
FS	3	(2-4)	3	(3-4)	3	(3-4)

* Ratings based on a Likert scale where 1 = *not*, 2 = *slightly* 3 = *moderately*, 4 = *very*, and 5 = *extremely* accessible.

† System Design (SD), System Construction (SC), System Maintenance (SM), Water Chemistry (WC), Fish Health & Disease (FHD), Plant Pest, Disease, and Nutrient Deficiencies (PPD), Financial Record Keeping (FRK), Marketing Food Products (MFP), Food Safety (FS)

Table 4.4. Spearman correlation coefficients between experience, training, and information resource utilization.

Hobbyist		1	2	3	4
1	Years of Aquaponic Experience	--			
2	Number of Training Sources Used	**.415****[†]	--		
3	Number of Info Sources Used	**.357****	**.338***	--	
4	Stage of Development	**.384****	.016	.105	--
5	Composite Accessibility Score	.213	.052	.219	.082

Producer		1	2		
1	Years of Aquaponic Experience	--			
2	Number of Training Sources Used	.139	--		
3	Number of Info Sources Used	.108	**.245***	--	
4	Stage of Development	**.467****	.105	.152	--
5	Composite Accessibility Score	.127	.019	.084	-.065

Educator		1	2		
1	Years of Aquaponic Experience	--			
2	Number of Training Sources Used	**.396****	--		
3	Number of Info Sources Used	**.353****	**.302***	--	
4	Stage of Development	**.282****	**.311***	.111	--
5	Composite Accessibility Score	.054	.125	.016	.185

*$p \le 0.05$, **$p \le 0.005$; Bonferroni adjustment for multiple correlations to minimize risk of Type I error. ($\alpha = 0.05/ = 0.005$)

[†] Correlation strengths defined as very weak ($0.0 < \rho < 0.19$), weak ($0.2 < \rho < 0.39$), moderate ($0.4 < \rho < 0.59$), strong ($0.6 < \rho < 0.79$), or very strong ($0.8 < \rho < 1.0$) (Evans, 1996).

Table 4.5. Informational resources used by aquaponic hobbyists, producers, and educators.

Currently Used Resources	Hobbyist (n = 85)		Producer (n = 127)		Educator (n = 86)	
	Count	%	Count	%	Count	%
Internet/Videos	76	89	112	88	71	83
Books/Library	57	67	81	64	58	67
Classes/Workshops	39	46	80	63	52	60
Peer-Reviewed Journals	25	29	63	50	58	67
Other Growers	28	33	64	50	45	52
Social Media	44	52	63	50	36	42
Extension Publications	29	34	50	39	47	55
Manufacturers/Suppliers	32	38	61	48	28	33
Extension Agents	20	24	38	30	33	38
Consultants	5	6	44	35	21	24
Friends/Family	20	24	27	21	22	26
Desired Resources	**Hobbyist (n = 69)**		**Producer (n = 108)**		**Educator (n = 73)**	
Other Growers	31	45	40	37	28	38
Extension Agents	26	38	46	43	24	33
Classes/Workshops	31	45	35	32	26	36
Extension Publications	24	35	44	41	22	30
Manufacturers/Suppliers	31	45	31	29	24	33
Consultants	22	32	25	23	22	30
Peer-Reviewed Journals	24	35	37	34	12	16
Books/Library	12	17	18	17	8	11
Social Media	4	6	10	9	6	8
Internet/Videos	1	1	8	7	6	8
Friends/Family	4	6	5	5	7	10
Unused Resources	**Hobbyist (n = 72)**		**Producer (n = 101)**		**Educator (n = 73)**	
Friends/Family	41	57	72	71	46	63
Consultants	46	64	44	44	32	44
Social Media	24	33	40	40	35	48
Extension Agents	26	36	24	24	20	27
Manufacturers/Suppliers	10	14	22	22	21	29
Peer-Reviewed Journals	22	31	17	17	8	11
Extension Publications	17	24	19	19	8	11
Books/Library	9	13	17	17	10	14
Other Growers	12	17	10	10	4	5
Classes/Workshops	8	11	5	5	6	8
Internet/Videos	1	1	4	4	2	3

Table 4.6. Benefits and drawbacks of various information sources for aquaponics.

Information Source	Benefits	Drawbacks
Peer-Reviewed Journals	High quality information Peer-review accountability Internet-based Open access journals	Few publications available Not always relevant Hard to understand Cost Non-interactive
Extension Agents	Good information Interactive Provide hands-on assistance Provide training Networking potential	Few agents trained in aquaponics Low local availability
Extension Publications	Good information Easy to understand Internet-based High accessibility Free of charge	Few publications available Non-interactive Not always relevant Not well known Variation in quality
Internet Videos	Internet-based Highly accessible Easy to understand Free of charge	Potential for misinformation Variation in quality Non-interactive Not always relevant
Social Media	Internet-based Highly accessible Interactive Networking potential	Potential for misinformation
Friends and Family	Interactive	Potential for misinformation Not always relevant

Books and Library	Comprehensive High quality information	Non-interactive Not always relevant Few publications available Variation in quality
Workshops	Relevant information Provide hands-on assistance Provide training Interactive Networking potential	Cost Variation in quality Potential for misinformation
Consultants	Interactive Relevant information Networking potential	Cost Variation in quality Potential for misinformation
Suppliers	Interactive Relevant information Networking potential	Requires Purchase Variation in quality Potential for misinformation
Other Growers	Good information Interactive Relevant information Networking potential	Low availability Potential for misinformation May not be willing to help

Chapter 5

System design and production practices of aquaponic stakeholders

Abstract

This study assesses the current system design and production practices of the aquaponic industry, compares and contrasts these characteristics by user group, identifies trends for future development; and identifies aquaponics industry needs for future growth. Overall, aquaponic systems were largely homemade/do-it-yourself (DIY), especially for hobbyists, while producers and educators often used a hybrid of DIY and commercially available (turn-key) technology. Funding sources were primarily personal funds, government grants , and private investor funds. Coupled systems were the most popular overall, which included recirculating aquaculture systems and either deep-water culture or media bed hydroponic units. Plant lighting sources included sunlight, light emitting diode, and fluorescent. Water sources were typically municipal or wells . Vegetable produce was the most common product sold, followed by training and education, food fish, and microgreens. Tilapia (*Cichlidae*) was the most commonly grown fish species across all groups, followed by ornamental fish (e.g. koi and goldfish; *Cyprinidae*) with 16 other species being reported. The most commonly grown crops overall were lettuce, leafy greens, basil, tomatoes, peppers, and herbs with many additional lesser-grown crops reported.

Introduction

Aquaponics is an agricultural practice incorporating fish and plant production using aquaculture, horticulture, and/or hydroponic units and principles. Regular feeding of fish generates a nutrient effluent used to fertilize vegetable or other plant crops to reuse fish wastes preventing their release into the environment. Further, these integrated systems produce two products with one fish feed input (Palada et al., 1999; Pattillo, 2017a). Many aquaponic practitioners appreciate this approach for its resource efficiency (decreased energy consumption), environmental benefits (waste reduction, heavy metal sequestration, reduced greenhouse gas emissions), and their ability to produce healthy foods locally (Greenfeld et al., 2018).

Aquaponics is commonly practiced in greenhouses using coupled systems where water circulates from the aquaculture unit to the hydroponic unit and back to the aquaculture unit and continues this flow process indefinitely (Love et al., 2014; Pattillo, 2017 a & b; Palm et al., 2018). Recirculating aquaculture systems (RAS) save water with reuse efficiencies of 95% to 99% (Dalsgaard et al., 2013; Timmons and Ebeling, 2013). As little as 100 L of water is required to produce one kilogram of fish (Martins et al., 2010), compared to 5,000 to 20,000 L of water per kg of beef produced using traditional pasture and feedlot methods (IME, 2013). Feeding 15g to 100g of fish feed daily can support one square meter of crops, depending on hydroponic method and crop resource demands (Rakocy et al., 2004; Endut et al., 2011; Goddek et al, 2015; Petrea et al., 2016). Fish feed conversion is efficient with ranges between 1 to 3 kg of feed required to produce 1 kg of fish (Fry et al., 2018). Aquaponic effluent supplementation to amend plant nutrient needs meets or exceeds hydroponic production output (Savadov, 2004;

Shul et al., 2016; Ayipio et al., 2019). Love et al (2015a & 2015b) reported two to nine kg of crops being produced from one kg of fish feed applied, plus the addition of 0.5 to 1 kg of fish produced.

Although forms of aquaponics have been practiced for centuries (Ebel, 2020), modern aquaponic research began in the late 1970's and has spread globally (Rakocy et al., 2004; Diver, 2006), with much of the activity being in the United States, Canada, Europe, and Australia (Love et al., 2014). Differences in geographic locations impact climatic conditions, which affect production strategy, input requirements, and environmental sustainability (Love et al., 2015b; Goddeck and Kröer, 2019; Ghamkhar et al., 2020; Avgoustaki and Xydis, 2020).

With few published accounts of industry practices and trends, it is important to document the current stakeholder groups, operation size and scale, investment requirements, crop species grown, production costs, profit potential and other factors that would affect one's decision to start an aquaponics business (Junge et al, 2017; König et al., 2018; Turnsek et al., 2020). Turnsek et al. (2020) provided insights into a number of immediate concerns and choices faced when initiating an aquaponic enterprise. The choice of fish and plants to produce might be easy decisions, but their choice sets off additional choices, such as quantity to produce, how to produce, and for whom to produce that then require decisions on system scale, system design, financing, permitting, regulations, marketing, and sales (Colander, 2006). Learning the idiosyncrasies of a system to produce marketable crops that comply with food safety and certification standards can be formidable. Effectively marketing the product at a price that promotes profitability may not be the reason one embarked into aquaponics, as it is often for enjoyment, self-sufficiency, sustainability, or environmental benefits (Love et al., 2014).

Aquaponic literature addressing operational and economic viability generally agrees that successful operations 1) are larger in scale; 2) obtain higher product selling prices; and 3) are realistic in their business plans (Greenfeld et al., 2018). Additionally, Love et al. (2015a) found aquaponic grower profitability was more likely if 1) aquaponics was their primary source of income, 2) operations were located in warmer climates, 3) gross revenue exceeded $5,000 annually, 4) operators were knowledgeable about aquaponics, and 5) operations sold non-food products like materials and supplies, training, agritourism, and consulting services.

The goal of this survey effort was to expand on previous aquaponic industry knowledge and update industry knowledge on practices used, facility scale, investment cost, and production inputs and outputs. Emphasis is on home gardener and hobbyists, for-profit and non-profit producers, and youth/adult educators. The objectives of this study were to 1) assess the current system design and production practices of the aquaponic industry; 2) compare and contrast these characteristics by user group; 3) identify trends for future development; and 4) identify aquaponics industry needs for future growth.

Materials and Methods

A digital survey (Qualtrics XM, Provo, UT, USA) was produced with considerations provided by Dillman (2007) and Fowler (2009), with the purpose of assessing the production practices of aquaponic stakeholders using a combination of original questions and prior industry surveys (Love et al. 2014; Villarello et al., 2016). Responses were collected using a mixture of question formats (e.g. Likert scale, categorical response, and text entry) to obtain qualitative and quantitative data. The survey format and question clarity were validated through a test run with the Aquaponics Association membership, then submitted to Auburn University's Institutional Review Board (IRB Protocol No: 19-544 EX 1912). Survey participants were solicited from a variety of aquaponics-focused email lists and social media groups, employing a snowball method to encourage greater participation beyond the reach of our network (Browne, 2005; Baltar and Brunet, 2012; Love et al., 2014). Data collection spanned from December 10, 2019 to June 4, 2020.

Respondents differentiated themselves by selecting a discrete stakeholder group – hobbyist, producer, or educator. The survey length varied based on the stakeholder group selected. All groups received the introductory block (21 questions), training/work hours (2), fish production (11), plant production (14), food safety (7), demographics (8) and the wrap-up block (4). Educators received 10 classroom usage question and producers received 23 additional questions about business and marketing. The survey duration was expected to be 20 minutes or more depending on the stakeholder group

Statistical Analysis

Qualtrics program data was exported to SPSS Statistic 26 (IBM, Armonk, NY, USA) for analysis. Tables and figures were generated using Excel (Microsoft 360, Redmond, WA, USA). To ensure the responses provided reliable data, they were manually and statically reviewed to eliminate illogical responses and extreme outliers. The central tendency and spread of the data are expressed using descriptive statistics (e.g. mean ± standard deviation (SD) or median (M) and inter-quartile range (IQR)) and responses were generalized using proportions (e.g. percentage). Continuous data were evaluated for differences among groups using a one-way Analysis of Variance (ANOVA) test with Tukey's Post-Hoc test for pairwise comparisons ($\alpha = 0.05$). The Poisson distribution was found to be most representative of the data due to its right-skewed nature, therefore, when appropriate, data was transformed with the natural logarithm function to meet normality assumptions for statistical analysis. Spearman's non-parametric correlation coefficient (ρ) was used to measure the strength and nature of relationships between variables using the Bonferroni adjustment for multiple comparisons ($\alpha = 0.05/n$) to reduce the risk of Type I error.

Results

Demographics, Background and Experiences

Because the number of potential respondents is unknown when using social media platforms, a reliable response rate could not be calculated. The number of respondents (n) per question varied and is noted in each table and figure. Out of 378 participants, 28% were hobbyists, 41% were producers, and 31% were educators. The median respondent was 55 to 64 (hobbyist) or 45 to 55-years of age (producers and educators), male, white/Caucasian, American, and employed full time (Table 1). The median aquaponic experience category overall was 3 to 5 years (Table 2). Seventy nine percent of hobbyists had less than 5 years of experience, with 24% having less than one year. Only 57% of the 321 respondents had systems that were currently in operation (Table 2). There was a significant positive, but weak correlation between the development stage and years of experience ($\rho = 0.370$, $p < 0.001$) (Evans, 1996). Out of 287 respondents, 60% anticipated increasing the scale of their current aquaponics operation over the next 5 years, with producers (76%) planning to scale-up most frequently (Table 2).

Location, Facilities, and System Design

Aquaponic stakeholder responses (N = 228) to their U.S. Department of Agriculture Plant Hardiness Zone (USDA ARS, 2021) locations found most operations were clustered in zones 5 through 9, which tends to encompass the temperate climate zone and the majority of the United States (Figure 1). The greatest density of producers were located in zone 8 (n = 22) and zone 9 (n = 16) and very few producers in zones 1, 2, 3, 10, 11, 12, and 13. Hobbyists were most densely clustered in zones 6 through 9, while educators were clustered in zones 5 through 8.

Background setting responses (N = 344) had 45% of stakeholders from rural areas, 27%, 26% and 2% from suburban, urban and industrial areas, respectively (Table 2). Hobbyists and producers were mostly located in rural settings, while educators were evenly distributed across rural, suburban, and urban settings. Only six respondents operated in industrial settings and were mostly producers (Table 2).

Respondents described the design of their aquaponic system as homemade or do-it-yourself (DIY), commercially available (turnkey), a hybrid of homemade and commercially available (hybrid) or designed by a consultant. Out of 313 responses, 55% were DIY, 25% were hybrids, and a consultant designed 12% and 7% were turnkey (Table 2). Hybrid and DIY categories together account for 80% of systems overall.

Hobbyists almost exclusively used DIY and hybrid systems, whereas turnkey systems were more commonly used by producers and educators.

Coupled systems recirculate effluent-rich water between the fish and plant portions of the system, while decoupled systems were defined as a water flow pattern that travels from the fish to the plants and does not return to the fish. Overall (n = 325), 84% of participants used coupled systems, 13% used decoupled systems, and 3% were unsure (Table 2). Hobbyist almost exclusively used coupled systems, and while producers and educators used coupled systems to a great extent, approximately 15% used decoupled systems (Table 2).

Aquaculture Unit

The most common fish production method (N=334) used by respondents was RAS systems (70%), with lesser use of ponds (8%), raceways (e.g. flow through) (7%), cages (e.g. net pen) (5%), biofloc systems (4%) and other systems (6%) (Table 3). Hobbyists almost exclusively used RAS, while producers and educators used a wider variety of systems, especially flow-through and pond systems, respectively.

Respondents selected from the 16 aquaculture system components in Table 3 to describe their system, and on average (± SD) producers used significantly more components (6.9 ± 2.9) than hobbyists (4.6 ± 2.3; $p < 0.001$) and educators (5.4 ± 2.5; $p = 0.001$). Hobbyists used backup generators, dedicated biological filers, environmental monitors, and protein skimmers much less than the other groups, and only slightly lower usage of aeration and automated feeders than other groups. Producers used solids settling clarifiers, water heaters, backup generators, dedicated biological filers, environmental monitoring systems, chillers, pure oxygen, ozone sterilization, and protein skimmers much more often than other groups, and used dedicated mechanical filters, airlift pumps and ultraviolet sterilization slightly more than other groups. Educators used heaters and chillers slightly less often than other groups and used automated feeders more often than other groups.

Growing environment responses (N=246) showed greenhouse (32%) or indoor (27%) environments were used most frequently to grow fish overall, followed by outdoors (17%) or under a shade structure/canopy (13%), while only a few used high tunnels (5%) (Table 3). Producers and educators used a greenhouse more frequently than hobbyists did. Use of indoor and outdoor production environments was similar across groups. Hobbyists used shade structures more frequently than producers and educators. Producers used high tunnels more frequently than hobbyists and educators. The average number of fish growing environments used per participant was 1.2 ± 0.5 for hobbyists, 1.3 ± 0.8 for producers, and 1.4 ± 0.7 for educators, which was similar across stakeholder groups.

Horticulture Unit

Hydroponic unit choices (N=219) indicated that 71% of respondents used deep water culture systems (DWC) (e.g. floating rafts) and 64% used media beds (e.g. flood and drain), with fewer growers choosing the nutrient film technique (NFT) (26%), vertical towers (20%), drip irrigation (e.g. Dutch or BATO buckets) (19%), or wicking beds (17%) (Table 4). Hobbyists used media beds most frequently, followed by DWC. Producers and educators used DWC most frequently, followed by media beds, and NFT.

Educators used DWC and media beds most frequently, with NFT use slightly higher than other groups. Producers used drip irrigation more frequently than educators and hobbyists. On average, hobbyists used 2.2 ± 1.3 plant production methods, while producers used 2.3 ± 1.2 and educators used 2.3 ± 1.3, which was similar across groups.

Plant lighting sources used by respondents (N = 221) were similar among groups, with sunlight (79%) being most common, followed by light emitting diode (LED) (43%), and fluorescent (22%) (Table 4). Producers relied most heavily on sunlight and LED lights. Hobbyists and educators used sunlight, LED, and fluorescent lights primarily. The most common input for "other" light source was metal halide (n = 3, 1%). On average, hobbyists used 1.6 ± 0.7 light sources, while producers used 1.7 ± 0.9, and educators used 1.5 ± 0.7, which was similar across groups.

Respondents (n = 223) indicated the most common plant growing environments were greenhouses (51%), followed by indoors (28%), and outdoors (25%), with fewer growers using shade structures (15%) and high tunnels (12%) (Table 4). Producers used greenhouses most frequently, while indoor growing environments were used more frequently by hobbyists and educators. Producers and hobbyists used high tunnels more frequently than educators did. The "other" category included an in-ground greenhouse (walipini), home basement, laboratory, and classroom. On average, hobbyists used 1.3 ± 0.5 plant-growing environments, while producers used 1.4 ± 0.8, and educators use 1.3 ± 0.6, which was similar across groups.

Facility Size

The size distribution of combined fish and plant area footprint of hobbyist, producer, and educator aquaponic systems is presented in Figure 2. Size designations were ‘micro’ (< 10 ft^2),‘mini’ (10 to 50 ft^2), ‘home garden/demonstration’ (50 to 500 ft^2), ‘pilot scale’ (500 to 3,000 ft^2), ‘small commercial’ (3,000 to 22,500 ft^2), ‘large commercial’ (22,500 to 165,000 ft^2), and ‘industrial’ (>165,000 ft^2). Median facility size categories were ‘home garden/demonstration’ for hobbyists and educators and ‘pilot scale’ for producers.

Inputs

The amount of time respondents (N = 294) personally spent working with their aquaponic system on a weekly basis showed about half of the respondents spent 10 hours per week or less and 23% spending 11 to 20 hours per week (Table 2). The majority of hobbyists (71%) and educators (55%) spent less than 10 hours per week working on their systems and nearly all spent less than 20 hrs/wk. Producers tended to spend more time working with their systems, with 50% spending more than 20 hours/week and 20% spending more than 40 hours per week. Weekly time spent on system operation was weakly positively correlated with years of experience ($\rho = 0.272$, $p < 0.001$) and very weakly correlated with development stage ($\rho = 0.198$, $p = 0.001$) (Evans, 1996).

The most commonly used aquaponic water sources (N = 252) were municipal (47%) and well sources (44%), followed by rainwater (26%), and very few using surface water (5%) (Table 2). Hobbyists and educators tended to use municipal water most often, while producers most commonly used well water. Rainwater was used more frequently by hobbyists and producers than educators. Producers used surface water most frequently. Hobbyists (1.2 ± 0.4), producers (1.3 ± 0.5), and educators (1.4 ± 0.6) reported using multiple water sources per operation, which were not significantly different among groups.

Overall, the most frequently selected funding source (n=290) was personal funds (74%), followed by government grants (18%), and private investor funds (14%). Hobbyists mostly used personal funds and credit cards (Table 2). Producers mostly used personal funds, investor funds, and bank or government loans. Educators mostly utilized personal funds, government grants, and private grants. Hobbyists used 1.1 ± 0.2 funding sources per participant, which was significantly lower than producers (1.7 ± 1.2) ($p < 0.001$) and educators (1.4 ± 0.7) ($p = 0.021$).

Products Sold

Selling aquaponic products (N = 300) occurred with 35% of respondents, while 65% did not sell products. The majority of hobbyists (93%) and educators (71%) did not sell products, but 57% of producers did. Notably, only 57% of all survey respondents were currently in the production stage. Vegetable produce was by far the most common product sold, followed by training and education, food fish, and microgreens (Figure 3). To a lesser extent, materials, supplies, and compost were sold, with very few respondents selling ornamental plants, composting worms, ornamental fish, worm castings, fish emulsion, and black soldier flies. The majority (61%) of product categories sold across groups did not include food fish or vegetable crops. Hobbyists most frequently sold vegetable produce, food fish, and ornamental fish (Figure 3). Producers sold vegetable produce, food fish, microgreens, and training and education most frequently. Educators sold vegetable produce, training and education. Hobbyists sold 2.0 ± 0.9 products per respondent, while producers sold, 3.7 ± 2.2, and educators sold 2.3 ± 1.1 per participant, which was not significantly different between stakeholder groups.

Hobbyists, producers and educators selected fish species they produced from a list of commonly grown aquatic animals in aquaponics (Figure 4). The average number of species grown per producer was 1.6 ± 0.9 for hobbyists, 1.9 ± 1.3 for producers, and 1.9 ± 1.6 for educators, which was not significantly different between stakeholder groups. Tilapia (*Cichlidae*) was by far the most commonly used fish species across all groups (57%), followed by ornamental fish (e.g. koi and goldfish; *Cyprinidae*) (37%). To a lesser extent "other" species, catfish (*Ictaluridae*), bluegill and other sunfishes (*Centrarchidae*), trout and salmon (*Salmonidae*), and crayfish, prawn, and shrimp were grown. Very few respondents used striped bass (*Moronidae*), baitfish, perch and walleye (*Percidae*), largemouth bass (*Centrarchidae*), common or grass carp (*Cyprinidae*), barramundi (*Latidae*) or jade perch (*Terapontidae*). Hobbyists grew ornamental fish more frequently than other groups. Producers grew tilapia, other species, trout and salmon, catfish, and sunfish more than other groups. Educators most commonly grew tilapia and ornamental species.

Hobbyists, producers and educators selected plant varieties they produced from a list of commonly grown crops in aquaponics (Figure 5). The average number of crops grown per participant was 6.2 ± 2.9 for hobbyists, 6.1 ± 3.2 for producers, and 5.3 ± 2.4 for educators, which was not significantly different between stakeholder groups. The most commonly grown crops overall were lettuce (83%), leafy greens (81%), followed by basil (73%), tomatoes (58%), peppers (44%), and herbs (43%). Lesser-grown crops were cucumber (35%), strawberries (32%), microgreens (31%), chives (31%), "other" (24%), flowers (18%), eggplant (17%), root crops (14%), and cannabis (6%). Lettuce was produced less by educators than hobbyists or producers, whereas leafy greens were produced at similar frequencies across groups. Hobbyists grew cucumbers, strawberries, flowers, peppers, and eggplant more commonly than the other groups. Producers grew herbs and microgreens most commonly. Educators produced basil most frequently.

Discussion

Background, Experience and Setting

Similar to Love et al. (2014), about four out of five respondents in this study came from the U.S., and the majority were educated white males. In this study, 41% of participants were producers compared to only 32% reported by Love et al. (2014). In this study, there were 56 self-identified producers in the US. The experience level of the respondents overall was relatively low, with 19% having less than one year, 38% having less than 3 years, and 66% having five years or less. Love et al. (2014) reported 89% having less than 5 years of experience, 52% with less than 3 years, and about 26% with one year or less. Love et al. (2014) reported about 5% of respondents with more than 11 years of experience, compared to about 11% of respondents in this study, indicating some level of retention over time.

The least restrictive production environment is rural, but access to inputs, infrastructure, and markets may be restricted (Tomlinson, 2015). Food deserts and poverty in urban environments see aquaponics as an agricultural solution to them (Tomlinson, 2015). Zoning restrictions and permits may be an issue for aquaponics in urban, suburban, and industrial environments (Tomlinson, 2015). However, appropriate tax incentives could incentivize industrial environments become prime contenders for major aquaponic production sites, as they have needed infrastructure and proximity to markets. Educators in rural, urban, and suburban setting are using aquaponic systems to teach Science, Technology, Engineering, Agriculture and Math (STEAM) topics (Hart et al., 2014; Genello et al., 2015; Junge et al., 2014).

Plant hardiness zone

Aquaponic locations with more stable environments and low seasonal variation in temperature are more efficient with relation to energy consumption and nitrate uptake by plants (Goddek and Kröer, 2019). Over 88% of environmental impacts from cold weather aquaponic systems are related to heat, electricity, equipment, and fish food (Ghamkhar et al., 2020). Farming in well-insulated buildings where the growing environment can be regulated is one cold weather adaptation that when combined with vertical production can maximize space and heating efficiency (Eaves and Eaves, 2018; Avgoustaki and Xydis, 2020). Indoor operations are dependent on artificial light for plant growth and electrical usage can be seven times higher than in a greenhouse (Avgoustaki and Xydis, 2020). In this study, operations were clustered in the temperate and subtropical climate zones, which influences the species of fish and plants that can be easily grown.

Do-It-Yourself vs Turnkey Operations

At present, many of the commercially available systems are too costly to provide an acceptable return on investment (ROI), which has led growers to develop their own systems. Eighty percent of aquaponic systems were DIY in this study, which is similar to the findings of Love et al. (2014, 2015a) and Genello et al. (2015). The self-design of systems will likely continue, especially for hobbyists, and this market could be expanded with the development of benchtop and backyard systems that are readily available and affordable. However, for producers the market is likely shifting toward greater use of commercially available systems and components as the industry grows and matures, which was seen by the elevated use of consultants and turn-key systems by producers and educators in this study.

Coupling design

Matching species needs and tolerances is critical for a coupled aquaponic system (Goddek et al, 2015). However, the aquaculture and hydroponic components can be separated, or decoupled, to allow for independent management of system parameters to optimize production in both components (Monsees et al., 2017). Strategies for decoupling include multi-loop recirculating systems (Suhl et al., 2016; Goddek and Körner, 2019) and drain-to-waste irrigation systems (Pattillo et al., 2020; Pickens et al., 2020). The vast majority of respondents used coupled systems; however, 15% of producers and educators used decoupled systems. As the decoupled approach to aquaponics becomes more researched and accepted it is likely that growers will shift toward decoupled systems because of the flexibility and control it offers (Yep and Zheng, 2019). Additional strategies like drip irrigation of field crops using aquaponic effluent, characterized as ‘aquaponic farming’, may prove useful to farmers especially during the growing season (Palm et al., 2018; Pattillo et al., 2020).

Aquaculture Unit

Similar to Love et al. (2014), the most common aquaculture production method in this study was recirculating systems, which were made from a variety of materials, with a preference for round plastic tanks. Greenhouses and indoor environments were used most frequently to grow fish. There was a range in system component usage, but most respondents used pumps and aeration, mechanical and biological filters, water heaters and backup generators. As species needs for water quality, solids removal, temperature, disinfection, swimming space, as well as management considerations like harvesting and routine maintenance, and especially production cost will greatly affect system design (Pattillo 2017b).

Growing Environment

The growing environment (Pickens and Danaher, 2016), hydroponic unit (Pickens et al., 2016), and lighting source (Oliver et al., 2018) make up the horticulture production unit (Pattillo 2017a). In this study most horticulture units were greenhouses, followed by indoors and outdoors environments. This is similar to the findings of Love et al. (2015a) who reported that plant production was strictly either in a greenhouse (31%) or in a greenhouse in combination with other indoor and/or outdoor facilities (41%). Genello et al. (2015) reported that educators grew plants outdoors (47%), in a greenhouse (46%), indoors (28%), or on rooftops (3%). Three quarters of hobbyist's systems, however, were located at their home, either outdoors (50%), indoors (19%), or in a greenhouse (33%) (Love et al, 2015c). Greenhouses are among the most expensive production environments, but allow growers to control temperature, humidity, and light intensity as well as reduce pest and weather damage to crops (Pickens and Danaher, 2016; Kaiser and Ernst, 2016). Warehouses are examples of indoor production environments and may be a viable option in colder climates, especially for out-of-season production when heating costs outweigh lighting costs (Avgoustaki and Xydis, 2020).

Hydroponic Unit

Types of hydroponic units include deep water culture (DWC or floating rafts), media beds (flood and drain or continuous flow), nutrient film technique (NFT), and drip irrigation (Dutch or Bato buckets and field crops), with growing interest in vertical tower production (Avgoustaki and Xydis, 2020), wicking beds (Semananda et al., 2020), and aeroponics (Love et al., 2014; Goddek et al, 2015; Pickens et al., 2016; Pattillo, 2017a). In this study, the most common strategies were DWC and media beds, which aligns with the findings of Love et al. (2104). Media beds tend to be more common with hobbyists and educators who have smaller scale systems because of their simplicity of design and flexibility in production (Genello et al., 2015; Love et al., 2015c). Producers tend to use larger systems that incorporate DWC because of ease of cleaning, crop maneuvering through the system, and flexibility in harvest (Pickens et al., 2016).

Leafy greens are typically grown in DWC while vining crops tend to be grown in media beds (Pattillo 2017a). The NFT method is also common, but presents management challenges, especially with clogging in the system (Pattillo 2017a). Vertical production units, while space efficient, tend to have similar clogging and pump failure challenges to NFT systems (Pattillo 2017a). Drip irrigation systems like Dutch buckets provide a modular production solution for vining crops like tomatoes (Pickens et al., 2020) and cucumbers (Blanchard et al., 2020) and can also be adapted for outdoor soil crop production (Pattillo et al., 2020).

Lighting

In this study, respondents took advantage of sunlight and energy efficient LED lighting most often (Table 4). The expense of constructing a greenhouse environment and maintaining optimal light intensity, duration, and temperature for plant growth can be costly and logistically challenging. Sunlight is the ideal lighting source because it is free and provides much needed heat. Temperature control is much more manageable in indoor environments but requires the use of grow lights. LED grow light technology has made large advances in recent years, making it an affordable solution for growers. Plants grown under LED lighting tend to achieve greater production biomass under the same conditions than other artificial lights with lower energy consumption (Oliver et al., 2018).

Facility Size

The variety of stakeholder groups and production units yielded differences in system size, which aligned with Love et al. (2014). Production facility size is related to its output capacity, markets served, cost of production, and economic viability with larger facilities tending to have lower per unit cost of production (Xie and Rosentrater, 2015; Quagrainie et al., 2017). Hobbyist and educator system size was similar, whereas producer systems tended to be larger. König et al. (2016) suggested that facilities need to be at least 1,000 m^2 (10,764 ft^2) to be profitable, which would encompass the area of approximately three to four standard greenhouses. All 17 respondents meeting these criteria were producers, representing 19% of the producer group. If this is indeed the minimum size to achieve profitability, the overwhelming intent to scale up (76% of producers) is well justified.

Scale up intent

Most respondents intended to increase their system size, which is a clear motivation for producers who need to reach an economically viable production scale (Love et al., 2015a; Tokunaga et al., 2015; Xie and Rosentrater, 2015; Quagrainie et al., 2017). However, motivations for hobbyists may involve space availability, personal time, food needs, personal drive, and disposable income (Love et al., 2014 & 2015c). Educators are more often motivated by the interest level of their students, availability of lesson plans, work time availability, the support of their administration, and the availability of space and funding (Hart et al., 2014; Genello et al., 2015). The relatively strong intention to increase the facility scale across all groups indicates growth potential for the aquaponic industry. Understanding the considerable uncertainty about scaling up by hobbyists and educators is an issue that will need to be addressed going forward.

Labor

Labor costs can be quite high for aquaponic producers, making up 49% of the total operating budget (Quagrainie et al., 2017) and determining economic viability (Love et al., 2015b). Larger facilities were shown to require more labor but development of automation, data modeling and environmental sensing equipment to reduce labor and energy costs will be a major focus of future aquaponic innovation (Junge et al., 2017; Kyaw and Ng, 2017; Baganz et al., 2020). In this study, producers devoted more time to their systems than hobbyists or educators, which aligns with the fact that their facilities tended to be much larger.

Water Source

The mineral composition and physiochemical properties of water impacts the productivity of the system, especially within nutrient dynamics and nitrogen cycling (Timmons and Ebeling, 2013; Pattillo 2017a). Municipal and well water are the highest quality and readily available but chemical additives may exist that are non-conducive to plant or fish growth. Hobbyists commonly incorporate rainwater harvesting to enhance their operation's sustainability (Love et al., 2014), but due to biosecurity and food safety regulations it is generally discouraged to utilize untreated rainwater and surface water that may harbor living organisms and pathogens (Hollyer et al., 2009; Fox et al., 2012; Pattillo, 2017a). In this study many participants used more than one water source, including municipal water and well water, followed by rainwater, with a few using surface water (e.g. ponds or streams), which is similar to the findings of Love et al. (2014).

Funding Sources

Access to capital is a major barrier for entry of newcomers to commercial aquaponics due largely to the inaccessibility of bank loans to aquaponic farmers (Villarroel et al., 2016; Turnsek et al., 2020). Producers often use their own personal funds or find private investors, while educators may be successful with obtaining government grants, donations and selling education and produce (Genello et al., 2015; Villarroel et al., 2016).

In this study, personal funds were used in nearly three quarters of aquaponic operations. Hobbyists were almost entirely self-funded, while producers enhanced their capital pool with other private sources, and educators used grant funding. Loan officers tend to be uninformed about aquaponics or have concerns about financial risk and the lack of viable business examples, which constrains financing options for growers stems from unfamiliarity with aquaponics. Due to the capital-intensive nature of commercial aquaponics, loan opportunities must be granted for the industry to grow, yet these options will only exist when there is a low perceived risk to loan agencies (König et al., 2018). To reduce risk to private lenders, government-backed loans could be made available, allowing farmers to get the financing they need (Brewer, 2019; Greenfeld et al., 2020a). Interestingly, 9% of participants were able to secure government backed loans. This is in contrast to previous surveys, which indicated that loans were not accessible for aquaponics (Villareal et al., 2016), indicating an increased knowledge and comfort level with this new technology.

Products Sold

Incorporation of agritourism, educational opportunities, and selling non-food products related to aquaponics is common practice to generate a profit (Junge et al., 2017). Approximately, one-third of respondents in this study sold products, with only 57% currently in the production stage. Vegetable produce, microgreen and food fish were the most common products, but training and education to newcomers was a common "product" of these operations. Villarroel et al. (2016) found that only 12% of their respondents actually sold crops, while 24% sold materials and supplies, and 65%

provided aquaponic training and education. Love et al. (2015a) reported that commercial producers sold fish and plants (37%), materials and supplies (27%) or some combination of both (36%), and 47% of aquaponic farmers conducted other farming enterprises.

In this survey, tilapia was the most commonly raised aquaponic fish species, followed by ornamental fish, similar to Love et al. (2014). However, fish production tends to operate at a financial loss in these combined fish-plant aquaponic operations (Engle, 2015). Sale of non-food fish, particularly high-value ornamental species (e.g. koi), or longer-lived species that require long production periods (e.g. sturgeon) could be used on an industrial scale as an opportunity for aquaponics because of reduced sorting and harvesting costs. Alternative species that can be stocked at extremely high densities (e.g. *Clarias* catfish) may provide opportunities to maximize system profits by reducing initial infrastructure costs but could also increase operational costs and risks (Baganz et al., 2020).

Additionally, there was great diversity of aquatic species being used experimentally, especially enticing is the use of saltwater shrimp. Marine aquaponics is relatively new and not thoroughly researched. The main issue here is finding commercially valuable, salt-tolerant plant species. Mariscal-Lagarda et al. (2012) showed low salinity shrimp (*Litopenaeus vannamei*) production could be incorporated with tomatoes and Pinheiro et al. (2017) used biofloc technology in the integration of saltwater shrimp and sea asparagus (*Sarcocornia ambigua*). Aquaponic researchers have also integrated marine fish production with a nursery facility of *Spartina alterniflora* and *Juncus roemerianus*, for conservation and restoration of estuarine habitats (Joesting et al., 2016).

Proportionally, the most common crops in this study were vegetative, with lower use of fruiting crops, and very low use of rooting crops. Lettuce and leafy greens were produced more commonly in this study than reported by Love et al. (2014). Although participants commonly grew many crops (5 to 12 species), the proportion of growers producing herbs, tomato, pepper, and cucumber decreased compared to Love et al. (2014). Lettuce, leafy greens, and herbs are relatively high-value, have short growth cycle varieties, are well suited to aquaponics and are very common in commercial production (Bailey and Ferrarezi, 2017). Love et al. (2015a) reported a higher use of leafy greens and lettuce by commercial producers compared to other stakeholders, although, proportional use of these crops was similar among stakeholder groups in this study. Fruiting crops like tomato, pepper, and cucumber are high value vegetable crops, but do not afford the grower the same value proposition in commercial production (Bailey and Ferrarezi, 2017; Quagrainie et al., 2017). Rooting crops are not well suited to aquaponic production and food safety concerns about the edible portion contacting the fish effluent water tend to discourage their use (Hollyer et al., 2009; Fox et al., 2012). Few participants in this study indicated that they produced cannabis (6%), which is not surprising considering cannabis production has only recently been legalized in some U.S. States (Yep et al., 2020) and is still contentious in many states.

Conclusions

As the aquaponic industry matures, it is prudent to know aquaponic industry trends in systems used, production practices and aquaponic operational scale. This chapter tracks the industry status, advances, and challenges facing hobbyists, producers, and educators.

It appears that the aquaponic industry scale and production are increasing compared to earlier industry surveys. Diversification of fish and plant crops with emphasis on high value and low per unit production cost is a trend that, over time, will need to continue for this industry to be profitability going forward.

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Table 5.1. Demographic identifiers of hobbyists, producers, and educators responding to the survey.

Demographic Category		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Stakeholder Group		105	25	156	37	117	28
Age Group	18-24	1	2	1	1	0	0
	25-34	5	7	12	15	5	9
	35-44	10	15	15	19	11	19
	45-54	15	22	15	19	14	24
	55-64	20	29	25	32	20	34
	65-74	11	16	10	13	7	12
	>75	6	9	1	1	1	2
	Total	68	100	79	100	58	100
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	65	100	75	100	59	100
Education	≤ High school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	66	100	77	100	61	100
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	66	100	74	100	57	100
Ethnicity	Asian	4	5	4	5	3	5
	Black	1	2	7	9	6	10
	Hispanic	1	2	0	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	59	78	38	63
	Other	1	2	0	0	5	8
	Undisclosed	5	7	6	8	3	5
	Total	68	100	76	100	60	100
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	68	100	71	100	59	100
Primary Income Source	Aquaponics	0	0	21	28	2	3
	Other	68	100	53	72	56	97
	Total	68	100	74	100	58	100

Table 5.2. Experience, effort, system style, design, funding source, background setting, development stage and intent of scale-up by aquaponic stakeholders.

		Hobbyist		Producer		Educator	
		N	%	N	%	N	%
Years of Aquaponic Experience	< 1 year	25	24	29	19	16	14
	1-2 years	22	21	31	20	21	18
	3-5 years	35	34	38	25	30	26
	6-10 years	18	18	38	25	31	27
	11-20 years	3	3	15	10	10	9
	>20 years	0	0	4	3	9	8
	Total	103	100	155	100	117	100
Weekly Time Spent	0-10 hours	61	71	38	31	47	55
	11-20 hours	20	23	23	19	25	29
	21-30 hours	4	5	18	15	5	6
	31-40 hours	0	0	20	16	5	6
	41-60 hours	1	1	18	15	2	2
	> 60 hours	0	0	6	5	1	1
	Total	86	100	123	100	85	100
System Style	Coupled	85	92	114	84	75	85
	Decoupled	7	8	21	16	13	16
System Design	Do-It-Yourself	76	79	55	43	42	48
	Hybrid	17	18	39	30	23	26
	Consultant	1	1	23	18	14	16
	Turn-Key	2	2	12	9	9	10
	N	96		129		88	
Water Source	Municipal	33	40	26	26	35	49
	Well	24	29	42	42	21	30
	Rain	20	29	22	22	10	14
	Surface	2	2	6	6	2	3
		82		99		71	
Funding Source	Personal Funds	82	96	98	78	36	46
	Private Investment	0	0	35	28	7	9
	Government Grants	0	0	19	15	33	42
	Private Grants	0	0	16	13	17	22
	Loans	0	0	25	20	2	3
	Credit/Financing	5	6	10	8	2	3
	N	85		126		79	
Background Setting	Rural	46	47	79	54	31	31
	Suburban	34	35	25	17	35	35
	Urban	17	17	37	26	34	34
	Industrial	1	1	4	3	1	1
	Total	98	100	145	100	101	100
Development Stage	Researching	16	17	12	9	20	22
	Planning	17	18	38	28	14	16
	Constructed	6	6	8	6	7	8
	Operational	56	59	79	58	48	54
	Total	95	100	137	100	89	100
Intent to Scale Up	Yes	37	44	97	76	39	53
	Unsure	34	40	21	16	26	35
	No	14	16	10	8	9	12

* N is the number of participants that responded when there was more than one selection option

** Composite scores are the sum of Likert rankings for knowledge in nine topic areas. Max score, 45

Table 5.3. Aquaculture system components incorporated into aquaponic systems by hobbyists, producers, and educators.

	Hobbyist (N = 72)		**Producer (N = 102)**		**Educator (N = 62)**	
System Components	N	%	N	%	N	%
Water Pump	67	93	97	95	56	90
Aeration	58	81	95	93	54	87
Clarifier/Solids Settler	38	53	70	69	30	48
Heater	35	49	57	56	26	42
Backup Generator	15	21	66	65	29	47
Dedicated Biological Filter	18	25	60	59	25	40
Combination Solids/Biofilter	30	42	44	43	28	45
Environmental Monitoring	10	14	43	42	17	27
Dedicated Mechanical Filter	15	21	35	34	17	27
Automated Feeders	13	18	26	25	18	29
Airlift	13	18	25	25	11	18
Ultraviolet Sterilization	10	14	28	27	10	16
Chiller	7	10	20	20	4	6
Pure Oxygen	3	4	18	18	1	2
Ozone Sterilization	1	1	11	11	0	0
Protein Skimmer	1	1	5	5	3	5
Production Method	(N = 79)		(N = 112)		(N = 66)	
Recirculating	73	92	103	92	59	89
Pond	6	8	11	10	10	15
Biofloc	1	1	9	8	3	5
Flow-Through	2	3	15	13	5	8
Cage	0	0	10	9	7	11
Other	5	6	11	10	4	6
Growing Environment	(N = 77)		(N = 104)		(N= 65)	
Outdoors	18	23	22	21	15	23
Shade Structure	17	22	14	13	11	17
High Tunnel	4	5	11	11	2	3
Greenhouse	24	31	49	47	30	46
Indoors/Warehouse	24	31	36	35	25	38

Table 5.4. Horticulture production system components for aquaponic hobbyists, producers, and educators.

	Hobbyist (N = 68)		**Producer (N = 94)**		**Educator (N = 57)**	
Hydroponic Unit	N	%	N	%	N	%
Deep Water Culture	39	57	75	80	42	74
Media Beds	53	78	51	54	36	63
Nutrient Film Technique	15	22	25	27	18	32
Drip Irrigation	11	16	20	21	10	18
Vertical Towers	14	21	18	19	11	19
Wicking Beds	13	19	16	17	8	14
Light Source	(N = 72)		(N = 93)		(N = 56)	
Sunlight	54	75	78	84	43	77
Incandescent	2	3	2	2	0	0
Fluorescent	20	28	17	18	12	21
High Pressure Sodium	5	7	5	5	2	4
Metal Halide	3	4	8	9	4	7
Light Emitting Diode	28	39	45	48	21	38
Induction	0	0	1	1	0	0
Growing Environment	(N = 72)		(N = 92)		(N = 59)	
Outdoors	21	29	20	22	15	25
Shade Structure/Canopy	14	19	11	12	8	14
High Tunnel	7	10	16	17	3	5
Greenhouse	26	36	57	62	30	51
Indoors	22	31	22	24	18	31

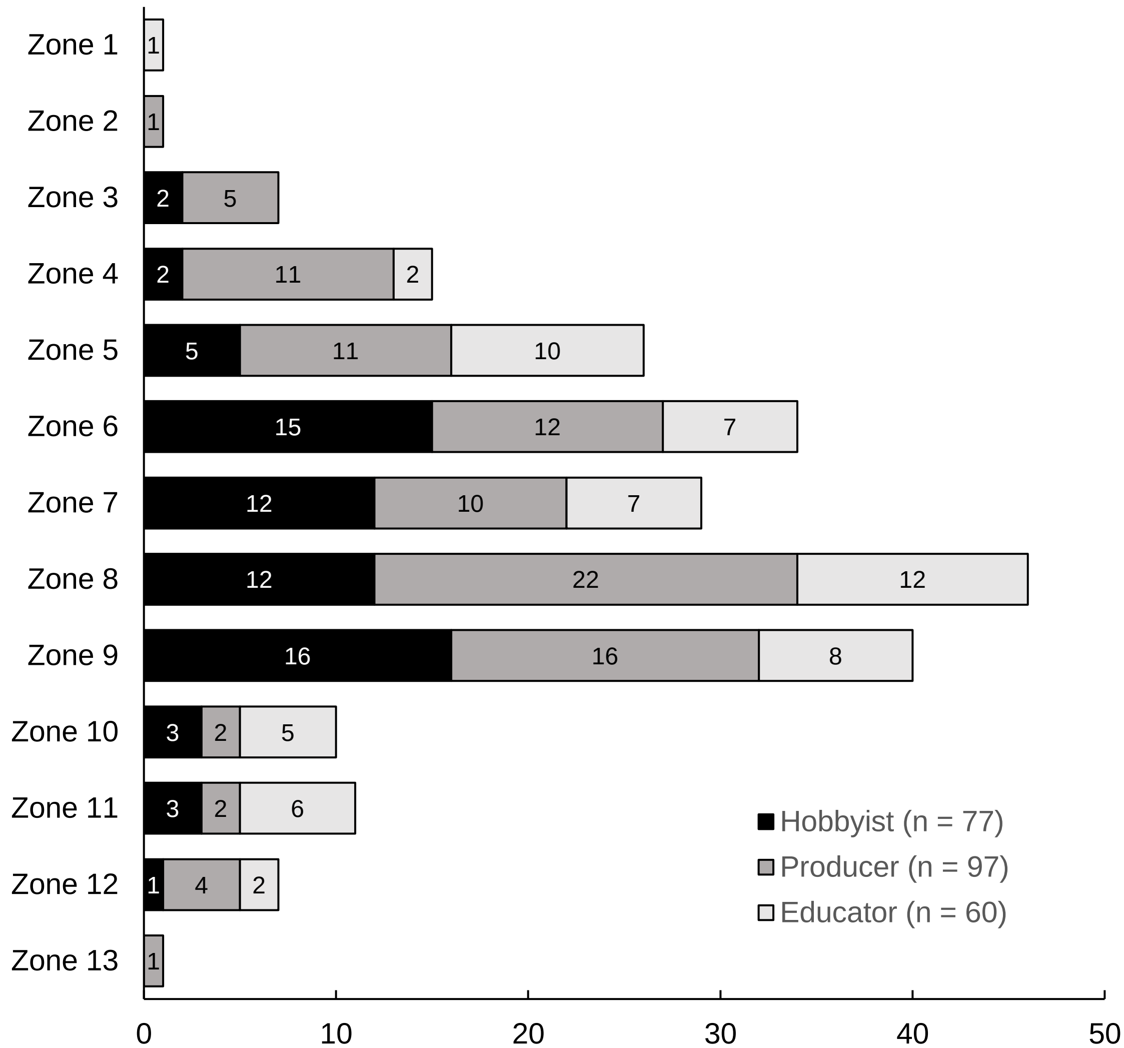

Figure 5.1. Number of U.S. aquaponic hobbyists, producers, and educators located in each of the USDA plant hardiness zones, where zone 1 represents the most polar and zone 13 is the most tropical climates. Numbers preset within the bars represent the total number of selections made by each stakeholder group.

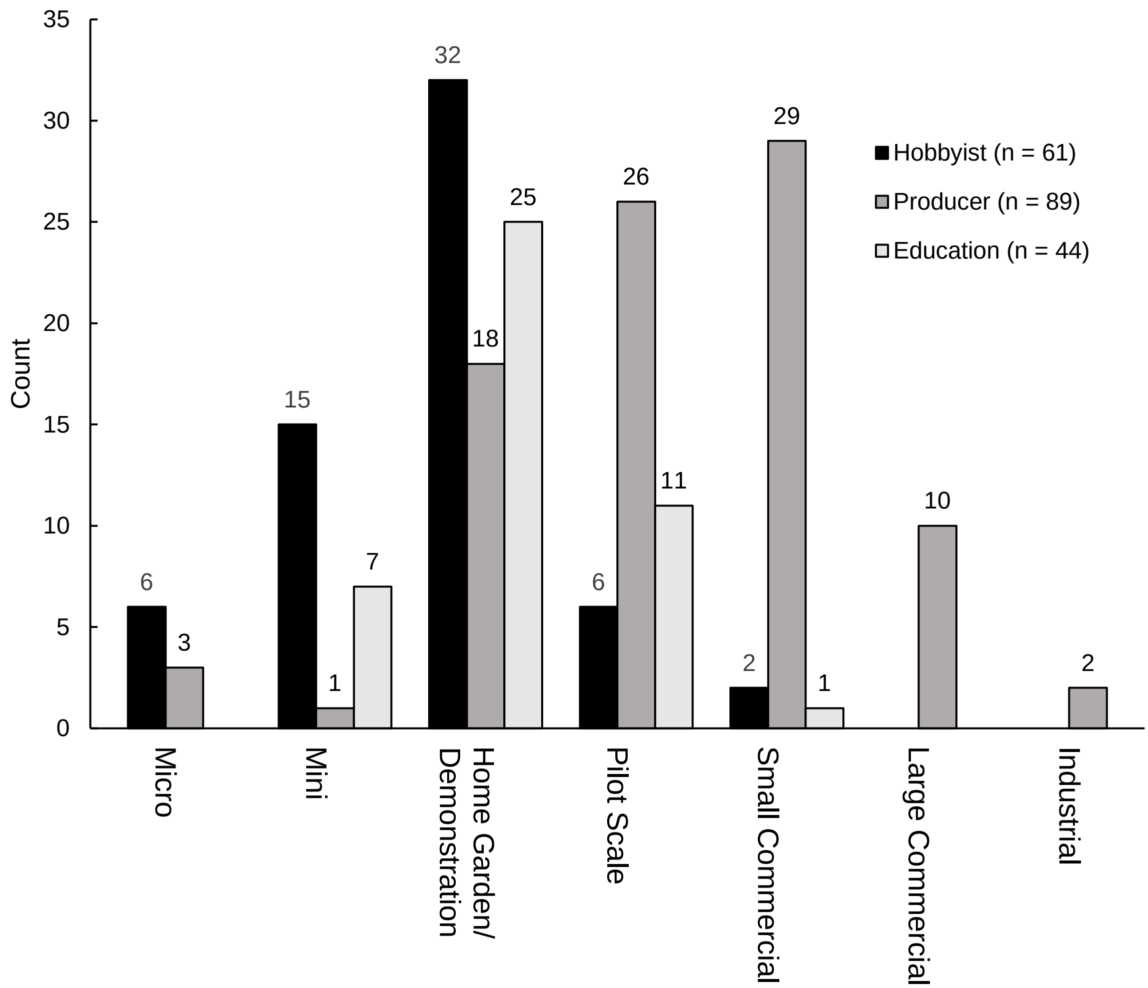

Figure 5.2. Size distribution of combined fish and plant area footprint of hobbyist, producer, and educator aquaponic systems. Size designations are ‘micro’ = < 10 ft^2; ‘mini’ = 10 to 50 ft^2; ‘home garden/demonstration’ = 50 to 500 ft^2; ‘pilot scale’ = 500 to 3,000 ft^2; ‘small commercial’ = 3,000 to 22,500 ft^2; ‘large commercial’ = 22,500 to 165,000 ft^2; ‘industrial’ = >165,000 ft^2.

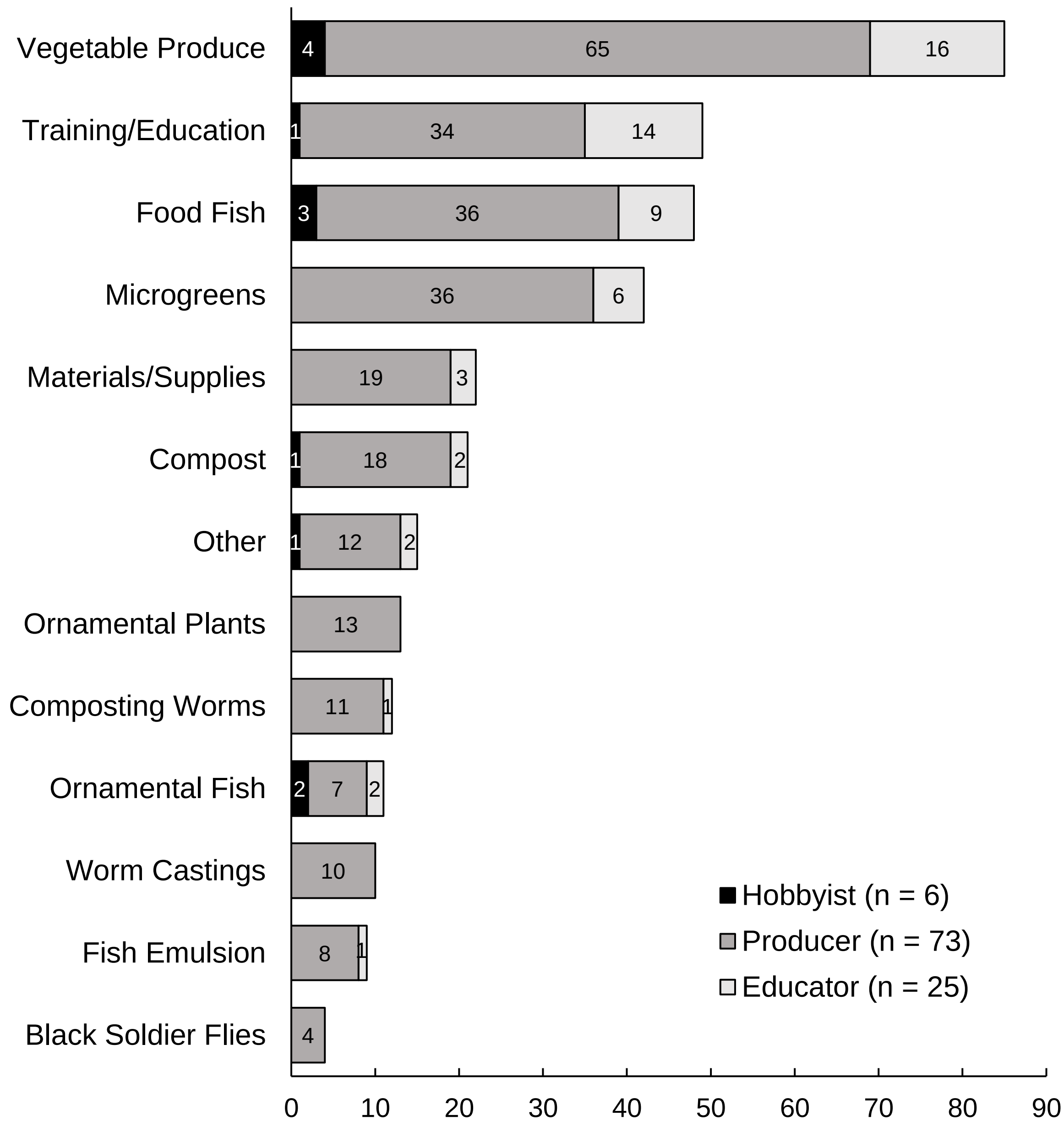

Figure 5.3. Frequency of product types sold by aquaponic hobbyists, producers, and educators. Numbers present within the bars represent the total number of selections made by each stakeholder group.

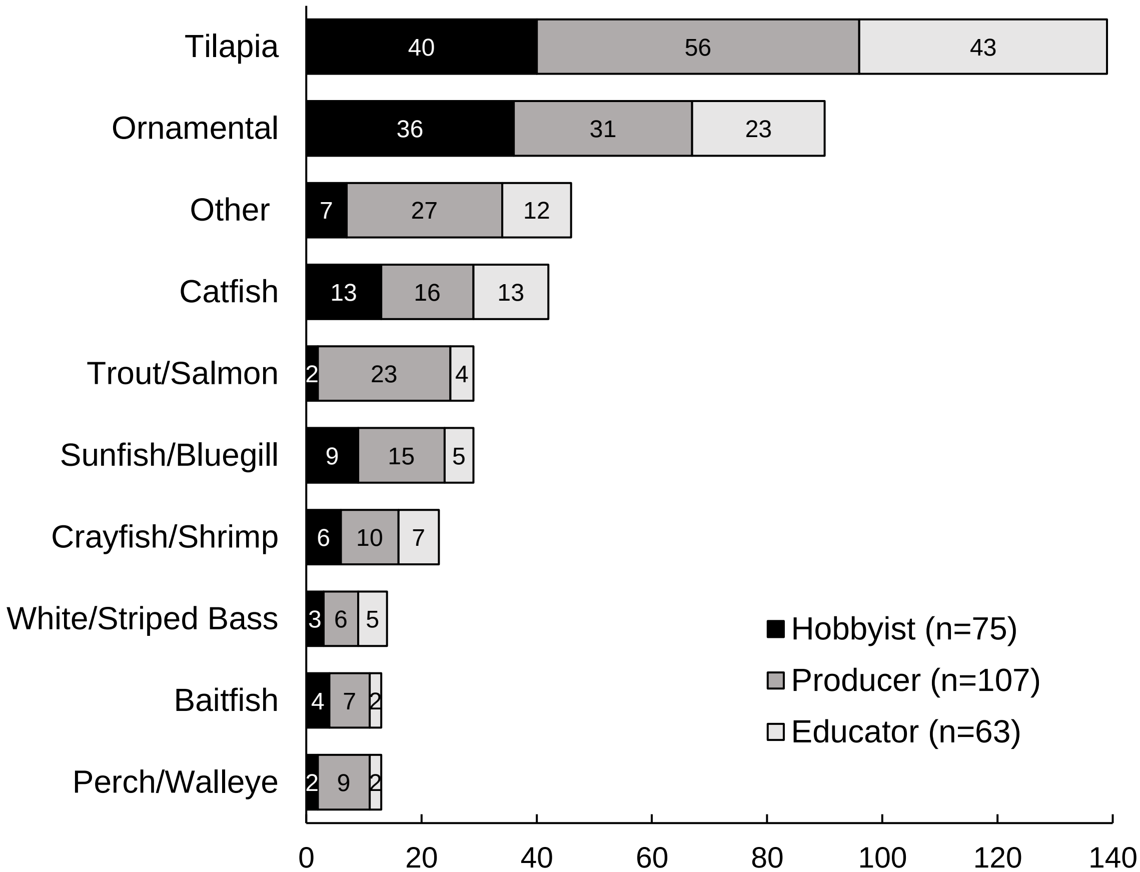

Figure 5.4. Frequency of fish species production by aquaponic hobbyists, producers, and educators. Numbers present within the bars represent the total number of selections made by each stakeholder group.

Note - “Other” fish species grown included white seabass, paddlefish, northern pike, crappie, pumpkinseed sunfish, heat-tolerant tiger trout, arctic char, white sturgeon, sleepy cod, tenca, snakehead, *Clarias* catfish, and mummichog.

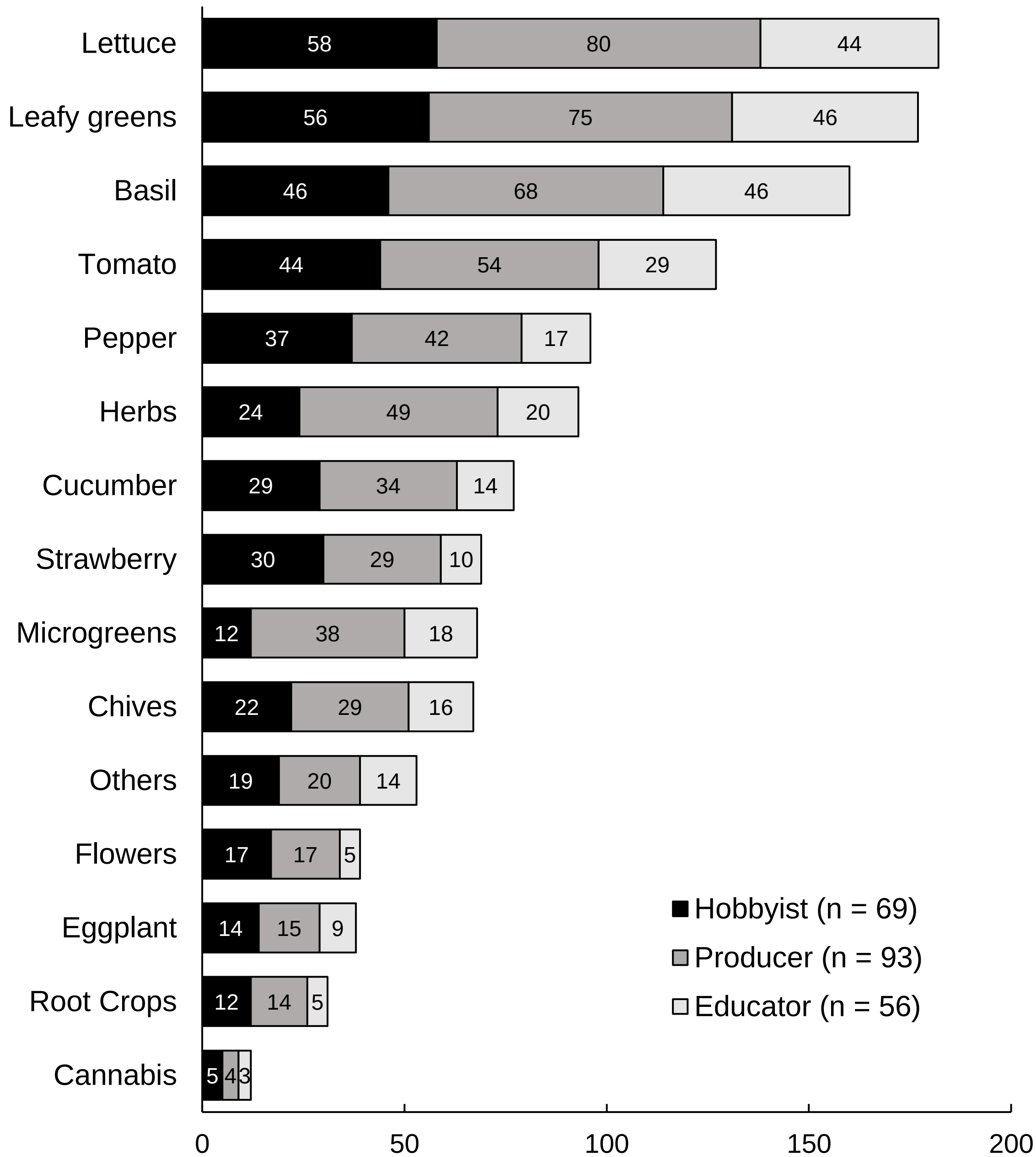

Figure 5.5. Frequency of plant species production by aquaponic hobbyists, producers, and educators. Numbers present within the bars represent the total number of selections made by each stakeholder group.

Note - “Other” crops grown by participants included aloe, banana, bay tree, beans, bok/pak choi, brewer's hops, broccoli, cauliflower, celery, cherry tomato, chili pepper, corn, cilantro, duckweed, edible flowers, ginger, green beans, kale, luffa, mango, medicinal herbs, melons, mint, *Momordica charantia*, okra, papaya, parsley, peanuts, peas, pineapple, pumpkins, raspberry, rosemary, squash, stevia, Swiss chard, turmeric, ulva, water lilies, watercress, and yam.

Chapter 6

System scale, production, and investment of aquaponic stakeholders

Abstract

This study investigates the scale of aquaponic systems operated by hobbyists, producers, and educators, demonstrates relationships between facility area, volume, production output, and investment, and provides ratios of fish to plant production parameters. Production parameter data ranged greatly, with moderate to very strong positive correlations between fish and plant area, volume, production output, and investment. Fish and plant area, volume, annual production output and investment cost was greatest for producers. System sizes differed by background setting with rural systems generally being larger, had greater fish and plant production, and had greater investment cost than urban systems, with suburban systems falling in between. The relationship between system area and water volume, production output and investment were positive and linear when Ln-transformed. Regression modelling showed that producer systems generally had the greatest variance explained (highest R^2) in these parameters, and hobbyist systems had the least (lowest R^2). The ratio of plant area to fish area and plant to fish production output were highest for producers, demonstrating that producers tend to focus on plant production. Investment per unit area and volume was highest for producers, while investment per unit production was greatest for hobbyists. Greater industry-combined production area, volume, and invested dollars compared to previous studies suggests growth of the aquaponic industry.

Introduction

Aquaponics is an agricultural practice that integrates fish and plant production using principles of aquaculture and hydroponics. Nutrients generated from aquaculture act as fertilizer for plant growth, producing two products from one feed input (Palada et al., 1999; Pattillo, 2017a). Aquaponics is commonly practiced in greenhouses using coupled systems where water circulates back and forth from the aquaculture unit to the hydroponic unit indefinitely (Love et al., 2014; Pattillo, 2017 a & b; Palm et al., 2018). Many practitioners implement aquaponics due to its resource efficiency, environmental benefits, and their ability to produce healthy foods locally (Greenfeld et al., 2019).

Much of the aquaponic research to date has focused on technical aspects of production rather than economic viability (Goddek et al., 2015; Suhl et al., 2016; Quagrainie et al., 2017; Engle, 2015; Goddeck and Kröer, 2019; Turnsek et al., 2020). A primary challenge for aquaponic growers is deciding which fish and crops are preferred by the market or individuals. These choices then determine how much to produce and what technology is required or appropriate. These decision impact system scale, system design, financing, permitting, regulations, marketing, and sales (Colander, 2006). Production system size is directly related to production output potential and investment cost (Xie and Rosentrater, 2015; Quagrainie et al., 2017), however ranges of production and investment potentials are needed for new producers to generate realistic business plans (Engle, 2015). It is important to document the current operation size, production outputs, and investment requirements, which affect one's decision to start an aquaponics business (Junge et al, 2017; König et al., 2018; Turnsek et al., 2020).

The goal of this survey was to expand on previous aquaponic survey data and update industry knowledge on current practices, facility scale, investment cost, and production inputs and outputs, for identified stakeholder groups. This study investigates aquaponic system scale parameters by aquaponic hobbyists, producers, and educators; demonstrates relationships between facility area, volume, production output, and investment; provides ratios of fish to plant production parameters; provides ranges of production rates and investment per unit area and volume among stakeholder groups.

Materials and Methods

The data used for this study was collected using and electronic survey (Qualtrics XM, Provo, UT, USA) developed with methods recommended by Dillman (2007) and Fowler (2009). Survey questions represented a conglomeration of past aquaponic surveys and original questions (Love et al. 2014; Villarello et al., 2016) using a variety of input formats (e.g. Likert, binary, categorical response, and open response). The Aquaponics Association membership pre-tested the survey and provided revisions to ensure question clarity prior to Auburn University's Institutional Review Board approval (IRB Protocol No: 19-544 EX 1912). In keeping with IRB protocols, respondents received an information letter explaining study objectives, data collection and use, participant rights and confidentiality. The data collection period was December 10, 2019 to June 4, 2020. A snowball advertising method was used to solicit responses from various aquaponic-focused social media groups and professional societies, with sharing encouraged amongst peers to broaden the survey reach (Browne, 2005; Baltar and Brunet, 2012; Love et al., 2014).

Respondents selected their stakeholder group as either 1) ‘hobbyists’ and home gardeners, 2) for-profit and not-for-profit ‘producers’, or 3) ‘educators’ [e.g. college, kindergarten thru grade 12 (K-12), Extension, etc.]. Survey questions were parceled into blocks that were received differently by participants based on their choice of stakeholder group. All groups received the introductory block (21 questions), training/work hours (2), fish production (11), plant production (14), food safety (7), demographics (8) and the wrap-up block (4). Educators received 10 additional questions about their use of aquaponics in the classroom, and producers received two additional blocks consisting of marketing (6) and commercial business (17) questions. Depending on the stakeholder group, the survey could last 20 minutes or more.

Statistical Analysis

Data analysis was performed using SPSS Statistic 26 (IBM, Armonk, NY, USA). Figures were developed using Excel (Microsoft 360, Redmond, WA, USA). Response reliability was evaluated through manual review of responses and descriptive statistical analysis for detection of extreme outliers or illogical responses, resulting in their correction or exclusion on an analysis-by-analysis basis. Descriptive statistics were used to express the central tendency and spread of the data (e.g. mean ± standard deviation (SD) or median (M) and inter-quartile range (IQR)) and proportions (e.g. percentage) were used to generalize stakeholder responses. In this study ‘N’ is used to denote the total respondents answering a given question, while ‘n’ is the number of respondents answering the question from each stakeholder group. Differences among group means were evaluated using a one-way Analysis of Variance (ANOVA) test with Tukey's Post-Hoc test for pairwise comparisons ($\alpha = 0.05$). Pearson's correlation coefficient (r) was used to measure the strength and nature of relationships between sets of variables with Bonferroni adjustment for multiple comparisons ($\alpha = 0.05/n$) to reduce the risk of Type I error. Spearman's correlation coefficient (ρ) was used as a non-parametric alternative for ordinal data comparisons. Following Evans (1996), correlations were defined as very weak ($0.0 < r/\rho < 0.19$), weak ($0.2 < r/\rho < 0.39$), moderate ($0.4 < r/\rho < 0.59$), strong ($0.6 < r/\rho < 0.79$), or very strong ($0.8 < r/\rho < 1.0$). Regression analysis was used to evaluate trends in system scale data with proportion of variance explained by the regression reported as R^2. The Poisson distribution was found to be most representative of the data due to its right-skewed nature; therefore, when appropriate, data was transformed with the natural logarithm function to meet normality assumptions for statistical analysis.

Results

Demographics, Background and Experiences

The anonymous nature of data collection using social media platforms prevented an accurate response rate calculation as it was unknown how many people actually saw the survey but did not complete it. The number of respondents (n) per question varied and is noted in each table and figure as required. Survey participants (N = 378) self-selected as hobbyists (28%), producers (41%) or educators (31%). The bulk of respondents were 55 to 74-years of age, male, white/Caucasian, American, and employed full time, although large segments of hobbyists and producers were retirees (Table 1). The median aquaponic experience category overall was 3 to 5 years (Table 2). Seventy nine percent of hobbyists had less than 5 years of experience, with 24% having less than one year. Fifty percent of producers and 53% of educators had 3 to 10 years of experience. Years of experience was weakly correlated with hours per week worked ($\rho = 0.272$, $p < 0.001$), fish volume ($\rho = 0.221$, $p = 0.002$), and plant area ($\rho = 0.202$, $p = 0.013$).

The amount of time respondents (N = 294) personally spent working with their aquaponic system on a weekly basis varied by stakeholder group (Table 2). The majority of hobbyists (71%) and educators (55%) spent less than 10 hrs/wk working on their systems and nearly all spent less than 20 hrs/wk. Producers tended to spend more time working with their systems, with 50% spending >20 hrs/wk and 20% spending >40 hrs/wk. Weekly time spent on system operation was moderately correlated with a) fish production area ($\rho = 0.459$; $p < 0.001$), b) fish volume ($\rho = 0.435$, $p < 0.001$), c) fish production ($\rho = 0.488$, $p < 0.001$) and fish investment ($\rho = 0.444$, $p < 0.001$). Moderate to strong correlations existed between weekly hours worked and a) plant area ($\rho = 0.525$, $p < 0.001$), b) plant volume ($\rho = 0.461$, $p < 0.001$), c) plant production ($\rho = 0.618$, $p < 0.001$), d) plant investment ($\rho = 0.462$, $p < 0.001$).

The overwhelming majority of systems were coupled, although 16% of producers and educators operated decoupled systems (Table 2). Systems were most commonly located in rural settings (45%), although suburban (27%) and urban systems (23%) were also reported, while very few systems were in industrial settings (2%) (Table 2). Out of 287 respondents, 60% anticipated increasing the scale of their current aquaponics operation over the next five years, 28% were unsure, and 11% did not plan to scale up. Producers (76%) planned to scale-up operations most frequently (Table 2).

Facility Area

Understanding that this survey obtained only a subsample of the aquaponic industry, the total of all fish and plant production areas captured in this study was 446,161 ft^2 (N = 170) and 997,923 ft^2 (N = 152), respectively. Combined fish and plant areas ranged from zero (planning stage) to 400,000 ft^2, with median hobbyist, producer and educator production area being 112 ft^2, 1,980 ft^2, and 320 ft^2, respectively (Table 3).

Fish and plant production area were significantly greater for producers than hobbyists and educators ($p < 0.001$) (Table 4). Plant production area was greater in rural settings (M = 648 ft^2) than urban (M = 180 ft^2) ones ($p = 0.004$). Note that facilities in the industrial setting were excluded from analysis because there were too few responses to meet statistical test assumptions. The plant to fish area ratio (A_P / A_F = PFAR) was greater for producers than hobbyists ($p = 0.023$) and educators ($p = 0.019$) (Table 3). Strong to very strong positive correlations existed between fish and plant area and volume, production, and investment (Table 5).

Facility Volume

The sum of fish and plant production volume from all respondents was 7,694,681 gal (N = 186) and 5,973,986 gal (N = 124), respectively. Fish and plant production volume was significantly greater for producers than hobbyists or educators ($p < 0.001$) (Table 4). System volumes ranged from zero to 4.5 million gal, with medians presented in Table 3. Strong to very strong positive correlations existed between fish and plant volume and area, production, and investment (Table 5). A significant positive Ln-linear relationship

(N = 177; Adj. R^2 = 0.705; p < 0.001) existed between combined fish and plant production volumes and combined fish and plant production area. Overall, this relationship can be expressed as y = 0.890 x – 0.617, where y = Ln (system volume (gal)) and x = Ln (system area (ft^2)), but this relationship varied by stakeholder group (Figure 1a). Median fish and plant system volumes per unit area are presented by stakeholder group in Table 4. The fish to plant volume ratio (V_F / V_P = FPVR) was not significantly different among groups (Table 3).

Production Output

The sum of self-reported annual fish and plant production output for all respondents was 3.7 million lbs/yr (N = 115) and 8.7 million lbs/yr (N = 90), respectively. Individual farm production ranged from zero to 1.5 million lbs/yr for fish and zero to 5.0 million lbs/yr for plants. Median fish and plant production outputs by stakeholder group are provided in Table 4. Additionally, fish production output was significantly greater in rural settings (M = 300 lbs/yr) than urban settings (M = 40 lbs/yr) (p = 0.017). Strong to very strong positive correlations existed between fish and plant production and volume, area, and investment (Table 5). A significant positive Ln-linear relationship (N = 104; Adj. R^2 = 0.705; p < 0.001) existed between combined fish and plant production output when plotted against combined system area. Overall, this relationship can be expressed as y = 0.613 x + 2.270, where y = Ln (system production (lbs/yr)) and x = Ln (system area (ft^2)), but this relationship varied by stakeholder group (Figure 1b). The median plant to fish production ratio (P_P / P_F = PFPR), which would indicate the expected plant production yield compared to fish production yield, is provided by stakeholder group in Table 3.

Investment

The sum of fish system investment from all respondents (N = 152) was \$22.9 million and ranged from \$0 to \$10.0 million, while the total plant system investment (N = 105) was \$16.1 million and ranged from \$0 to \$10.0 million. Combined plant and fish investment was highest for producers (range \$250 to \$10.2 million), followed by hobbyists (\$75 to \$150,000) and educators (\$100 to \$100,000), with median investment levels provided in Table 4.

Combined investment per unit area ranged from \$0.03/ft^2 to \$111.11/ft^2 for hobbyists (n = 21), \$0.83/ft^2 to \$478.26/ft^2 for producers (n = 47), and \$0.57/ft^2 to \$221.34/ft^2 for educators (n = 22), with median levels being provided in Table 3. Combined investment per unit volume ranged from \$0.08/gal to \$16.67/gal for hobbyists (n = 21), \$0.01/gal to \$183.33/gal for producers (n = 47), and \$0.12/gal to \$151.52/gal for educators (n = 22), with median levels being provided in Table 3. Combined investment per pound of annual production ranged from \$0.49/lb/yr to \$300.00/lb/yr for hobbyists (n = 21), \$0.1/lb/yr to \$39,009.90/lb/yr for producers (n = 47), and \$0.14 to \$500.00/lb/yr for educators (n = 22), with median levels being provided in Table 3.

The fish investment and plant investment were greater for producers than hobbyists and educators ($p < 0.001$) (Table 4). Additionally, fish investment was greater in rural settings (M = \$15,000) than urban (M = \$2,400) ($p = 0.002$) or suburban settings (M = \$1,350) ($p < 0.001$), while plant investment was greater in rural settings (M =

$10,000) compared to urban settings (M = $750) ($p$ = 0.042). Median fish and plant total and per unit investment by area, volume, and production output are presented by stakeholder group in Table 4. Strong to very strong positive correlations existed between fish and plant investment and volume, area, and production (Table 5). A significant positive Ln-linear relationship (N = 135; Adj. $R^2 = 0.617$; $p < 0.001$) existed between combined fish and plant investment when plotted against combined fish and plant production area. Overall, this relationship can be expressed as y = 0.661 x + 0.324, where y = Ln (system investment ($)) and x = Ln (system area (ft^2)), but this relationship varied by stakeholder group (Figure 1c). Fish to plant investment ratios (I_F / I_P = FIPR) are presented by group in Table 3.

Discussion

Background and Experience

Similar to Love et al. (2014), approximately 80% of respondents were in the U.S. with a majority being educated, white, males, with 41% being producers. The experience level of the respondents overall was relatively low, with 66% having five years or less. However, compared to Love et al. (2014) who reported 89% having less than 5 years of experience, it appears that there may be an increase in grower retention over time.

Labor

Producers often worked more than 40 hours per week on their system personally, compared to less than 20 hours per week for hobbyists and educators, which aligns with the fact that their facilities tended to be much larger. According to Quagrainie et al.

(2017), labor requirements for various farm sizes ranged from 23 hr/day (small), 31.2 hr/day (medium), and 65.8 hr/day (large). Many operations employ a combination of full time, part time, and volunteer labor, which varies depending on facility size and goals (Love et al., 2015a). Labor costs can be quite high for aquaponic producers, making up 49% of the total operating budget (Quagrainie et al., 2017) and determining economic viability (Love et al., 2015b). Finding low-cost, skilled labor with good work is challenging. Increasing workforce development efforts at the high school or community college level would be advantageous to improving the skilled labor pool for the aquaponics industry.

Larger facilities were shown to require more labor but development of automation, data modeling and environmental sensing equipment to reduce labor and energy costs will be a major focus of future aquaponic innovation (Junge et al., 2017; Kyaw and Ng, 2017; Baganz et al., 2020;). Robots can perform repetitive tasks with greater speed and precision than manual labor, leading to greater consistency of product, reliability of results, and reduced human resource issues. There was a moderate correlation between fish area/volume and weekly time/labor and a strong correlation between plant area/volume and weekly time/labor, implying that plant production takes more labor than fish production. Automated technology for sowing seeds, transplanting, and harvesting, can greatly reduce labor needs.

Coupling Design

Overall, coupled systems were the most popular system style among all stakeholder groups. Respondents that used decoupled systems were primarily producers and educators. The benefits of a coupled systems are water, energy, and nutrient use efficiency; however, matching species needs, and tolerances is critical for a coupled aquaponic system (Goddek et al, 2015). For example, cold water fish species may not be compatible with warm weather plants, causing a reduction in productivity for one or the other. Additionally, pest and disease management options are limited because of the danger to either fish, plants, or beneficial bacteria. Decoupling the aquaculture and hydroponic components allows for independent management of system parameters to optimize production in both components as well as (Monsees et al., 2017). Shul et al. (2016) demonstrated the nutritive benefit of aquaculture effluent in a decoupled recirculating aquaponic system (‘DRAPS’), finding that hydroponic fertilizer requirements were reduced by 23.6% for tomatoes, equating to an additional 10.3 kg of tomato produce per kg of hydroponic fertilizer added. This configuration also allows for the use of insecticides when needed, potentially saving a crop and managing risk for farmers.

Background Setting

Systems located in rural setting tended to be the largest in this study. This is likely caused by a combination of lower land values and less restrictive zoning laws in rural areas; however, access to inputs, infrastructure, and markets may be restricted (Tomlinson, 2015). Residents of urban food deserts or areas of lower socioeconomic class view aquaponics as a potential source of fresh, local fish and produce (Tomlinson, 2015). Educators in rural, suburban, and urban settings are using aquaponic systems to teach Science, Technology, Engineering, Agriculture and Math (STEAM) topics (Hart et al., 2014; Junge et al., 2014; Genello et al., 2015). Land and infrastructure cost, zoning restrictions and permits may be an issue for aquaponics in urban, suburban, and industrial environments (Tomlinson, 2015), which falls in line with the diminished facility sizes observed in this study in urban and suburban settings. Additionally, land values in developed areas tend to be higher making agriculture cost-prohibitive. However, appropriate tax incentives could incentivize industrial environments become prime contenders for major aquaponic production sites, as they have needed infrastructure and proximity to markets.

Scale-up Intent

There was a relatively strong intention to increase the facility scale across all groups, but especially by producers in this study. This intent indicates potential growth of the aquaponic industry. The need to increase scale to reach an economically viable production level is a clear motivation for producers (Love et al., 2015a; Xie and Rosentrater, 2015; Quagrainie et al., 2017). However, there was also considerable uncertainty about scaling up, especially by hobbyists and educators, indicating a need to know why and address these issues. System scale-up motivations for hobbyists may involve space availability, personal time, food needs, personal drive, and disposable income (Love et al., 2015c). Educators are more often motivated by the interest level of their students, availability of lesson plans, work time availability, the support of their administration, and the availability of space and funding (Hart et al., 2014; Genello et al., 2015). Gaining insight into motivations relating to facility size could be an area of future research to assist newcomers in the decision-making process.

Facility Size

In this study, system area ranged from zero to 400,000 ft^2 (37,161 m^2) with a median of 400 ft^2 (37.2 m^2), and volume from zero to 4.5 million gal (17, 034 m^3) with a median of 1450 gal (5.5 m^3). Love et al. 2014 reported individual systems ranging from 3 gal to 600,000 gal and 0.01 m^2 to 18,580 m^2, with a median volume of 500 gal and median area of 15 m^2. The variety of stakeholder groups and production units yielded differences in system size, aligning with the findings of Love et al. (2014, 2015 a & c) and Genello et al. (2015). According to Love et al. (2015c) the median system size for hobbyists was 100 ft^2 and 350 gal, 1,300 ft^2 and 2,700 gal for producers (Love et al., 2015a) and approximately 200-750 ft^2 and 400-600 gal for educators (Genello et al., 2015). Production facility size is related to output capacity, markets served, cost of production, and economic viability with larger facilities tending to have lower per unit cost of production (Xie and Rosentrater, 2015; Quagrainie et al., 2017). According to Love et al. (2014) the scale of the aquaponics industry worldwide was estimated to have a combined system volume of 3.5 million gal (13,250 m^3), covering 28 acres (11 ha), based on 809 participant responses. In this study, the combined industry scale was 13.7 million gal (51,742 m^3), covering 33.2 acres (13.4 ha) based on 194 responses. Even though the number of respondents was lower in this study, the total area and volume was greater, indicating industry scale growth since the Love et al. (2013) study.

Maucieri et al. (2018) provided system scale designations ranging from 'micro' (<5 m^2), 'very small' (5-50 m^2), 'small' (50-200 m^2), 'medium' (200-1,000 m^2), and 'large' (>1,000 m^2). The 'large' facility designation fits the minimum criteria to be profitable according to König et al. (2016). Among the responses (N = 195) for facility area, 18% could be categorized as ‘micro’, 38% ‘very small’, 19% ‘small’, 15% ‘medium’, and 9% ‘large’, of which, all (n = 17) were producers, representing 19% of the producer group. If the minimum facility footprint to be profitable is indeed 1,000 m^2 (10,764 ft^2), then the overwhelming intent to scale up (76% of producers) is well justified.

Median water volume per square foot ranged from 7.9 to 8.3 gal/ft^2 for fish and 2.5 to 4.5 gal/ft^2 for plants. The median ratio for plant area to fish area ratio (PFAR) ranged from 1.3 to 4.8, indicating that more area was devoted to plants. Villarroel et al. (2016) reported an average PFAR of 3.5 to 1, with larger scale systems being decoupled. Fern (2013) predicted a PFAR of approximately 4:1 would be required to absorb the nutrients produced in a biofloc tilapia production system. Likewise, the FPVR ranged from 0.8 to 1.5, indicating that plant system volumes were similar to fish system volumes. Hobbyist and educator system size was similar, whereas producer systems tended to be larger.

Production Output Rates and Ratios

In this survey, total fish production was 3,690,230 lbs/yr, while overall median fish yield per operation was 105 lbs/year. Total plant production was 8,786,092 lbs/yr, with an overall median plant yield per operation of 500 lbs/yr. Production rates per unit area and volume indicated the scaling factor that should be applied to various aspects of one’s system during the planning process to formulate a strategy for success. Median fish production ranged from 0.1 to 0.5 lbs/gal/yr. A typical stocking density for fish in a recirculating aquaculture system could range from 0.1 to 1.0 lbs/gal or greater, with the fish production cycle ranging from six to 18 months or more depending on fish species (Timmons and Ebeling, 2013). Median plant production ranged from 0.8 to 5.4 lbs/ft^2/yr/. Kaiser and Ernst, 2016) reported a typical 3,000 square foot greenhouse was able to produce 5,900 marketable heads of hydroponic lettuce per production cycle, with eight cycles per year. At a typical harvest weight of 0.5 to 1.0 lbs per head, this would result in lettuce production of 7.9 lb/ft^2/yr to 15.7 lb/ft^2/yr. Barbosa et al. (2015) reported greenhouse lettuce yields of 41 ± 6.1 kg/m^2/yr (8.40 ± 1.25 lb/ft^2/yr) compared to conventional field-grown methods where yields were 3.9 ± 0.21 kg/m^2/yr (0.80 ± 0.04 lb/ft^2/yr).

The ratio for fish to plant production output indicated a relative measure of production output. The median PFPR ranged from 0.9 to 7.2, which indicated that plant production yield typically exceeded fish production output. Baganz et al. (2020) reported a PFPR of 2.1, while Love et al. (2015b) reported PFPRs that ranged from 2 to 5. Love et al. (2015a) suggested that the PFPR could be as high as 9:1.

Investment and Profitability

The financial investment in an aquaponic facility varies greatly by components used. In this study, aquaponic system investment ranged widely, from hundreds to hundreds of thousands of dollars, with a few producers investing millions. Median total system investment was $1,000 for hobbyists, $47,000 for producers, and $2,800 for educators. According to Love et al. (2015c) the median system investment for hobbyists was $50 to $999 the previous year, whereas producer median investment was $5,000-$9,999 in the previous year (Love et al., 2015a). Educator investment in facilities ranged from \$0 to over \$500,000 with a typical cost of entry of < \$5,000 in K-12 schools, and median investments of \$1,000 to \$4,999 in the previous year (Genello et al., 2015).

The rates of per unit investment provide general rules of thumb during the planning process to make sure that the prices paid for inputs are fair and that planning budgets contain realistic figures. In this study, median cost per square foot ranged from \$14.60 to \$23.60 on the fish unit and \$8.10 to \$17.80 in the plant unit. Likewise, median fish cost per gallon ranged from \$2.00 to \$3.60 and median plant cost per gallon ranged from \$2.50 to \$9.60. The median FPIR ranged from 0.6 to 1.3 indicating the amount of money spent on system infrastructure was similar in both the fish and the plant units.

The following comparisons are presented in an effort to validate the figures generated in this study. Engle (2015) summarized the investment, operational and production costs of several studies in Hawaii (Baker, 2010; Tokunaga et al., 2015) and the U.S. Virgin Islands (Bailey et al, 1998), revealing that aquaponics can be economically viable in tropical environments. Tokunaga et al. (2015) reported the system fish unit volume to plant unit area to range between 59.9 L/m^2 and 66.4 L/m^2, with approximate PFAR = 13.5:1 and FPVR = 0.3:1, assuming a 0.22 m plant raceway depth. The investment cost for the University of the Virgin Islands (UVI) system, which includes four fish tanks (8,242 gal) and six plant culture raceways (5,167 ft^2, 23,205 gal was \$135,852 (\$26.29/ft^2) and with additional required infrastructure (e.g. fish hatchery, plant nursery, rain catchment, office, labs, cold storage and farm vehicles) the investment cost totaled \$285,134 (\$55.18/ft^2) for the commercial aquaponic system (Bailey et al., 1998). The UVI system had a fish unit volume to plant unit area ratio of 140 L/m^2, a

PFAR = 8.45:1 and a FPVR = 0.36:1. A system representative of the subtropical climate was described by Fern (2013), using a low-tech, decoupled tilapia-cucumber aquaponic facility in Alabama, USA. The model facility included one fish greenhouse (2,880 ft^2) and one plant greenhouse (2,880 ft^2) (PFAR = 1:1) at $78,604 ($13.64/ft^2). However, a projected 4x scale-up for plant production was suggested by Fern (2013) (PFAR = 4:1) to improve nutrient uptake, production efficiency, and economic viability, which would cost $162,476 ($11.28/ft^2), for a breakeven total cost of tilapia at $1.16/lb and $0.25/lb to produce cucumbers. In contrast, Fern (2013) found the breakeven cost of tilapia production in an intensive indoor RAS system to be $1.59/lb to cover all costs. Kaiser and Ernst (2016) reported a typical investment cost for a hydroponic lettuce greenhouse facility could be over $10/$ft^2$ but could yield $10 to $25/$ft^2$ depending on crop and quality, resulting in a breakeven cost of production of $0.93/head covering all costs. Temperate climates have greater constraints for aquaponic profit due to heating cost in the winter (Love et al., 2015b). Love et al. (2015b) described a research-scale system using DWC with a PFAR = 4.7 and FPVR = 0.5, spending $12/kg of tilapia and $6/kg of crops to cover energy costs and selling their lettuce crops at $26.50/kg to make a profit in Maryland, USA.

System scale, initial costs, operating costs, and fish/plant sales prices are critical factors that determine profitability (Xie and Rosentrater, 2015; Quagrainie et al., 2017). Love et al. (2015a) noted that only 31% of commercial producers claimed to be profitable, while 55% predicted profit in the next 12 months, and 75% predicted profit within 36 months. Aquaponic literature addressing operational and economic viability generally agrees that successful operations are larger in scale, obtain higher product selling prices, and have realistic business plans (Greenfeld et al., 2019). Additionally, Love et al. (2015a) found aquaponic grower profitability was more likely if aquaponics was their primary source of income, operations were located in warmer climates, gross revenue exceeded $5,000 annually, operators were knowledgeable about aquaponics, and operations sold non-food products like materials and supplies, training, agritourism, and consulting services.

With this high infrastructure cost it is critical to select crops that maximize returns based on market value, production rate, and production area required, which is typically done with leafy greens (e.g. lettuce) and herbs (e.g. basil) (Bailey and Ferrarezi , 2017). According to Xie and Rosentrater (2015) economies of scale were observed with larger scale operations (> 75 m^2 growing area) obtaining higher plant sales prices (>$60/kg for basil). Quagrainie et al. (2017) also observed improved profit potential as facility scale increased for aquaponic systems in the Midwestern US. System scale efficiencies will be critical to the success of the aquaponics industry going forward.

Conclusions

The current study provides a comprehensive look at stakeholder systems scales, production outputs, and monetary investments made by various stakeholders. These factors were used to craft guidelines for proportions between the fish and plant units, production output potential and investment rates per unit area and volume. It appears that the aquaponic industry scale is increasing with larger production area, volume, and invested dollars than reported by earlier industry surveys. Attention to system scale optimization and diversification of fish and plant crops with emphasis on high value and low per unit production cost over time will be critical to profitability going forward.

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Table 6.1. Demographic identifiers of hobbyists, producers, and educators responding to the survey.

Demographic Category		Hobbyist		Producer		Educator	
		n	%	n	%	n	%
Stakeholder Group		105	25	156	37	117	28
Age Group	18-24	1	2	1	1	0	0
	25-34	5	7	12	15	5	9
	35-44	10	15	15	19	11	19
	45-54	15	22	15	19	14	24
	55-64	20	29	25	32	20	34
	65-74	11	16	10	13	7	12
	>75	6	9	1	1	1	2
	Total	68	100	79	100	58	100
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	65	100	75	100	59	100
Education	≤ High school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	66	100	77	100	61	100
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	66	100	74	100	57	100
Ethnicity	Asian	4	5	4	5	3	5
	Black	1	2	7	9	6	10
.	Hispanic	1	2	0	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	59	78	38	63
	Other	1	2	0	0	5	8
	Undisclosed	5	7	6	8	3	5
	Total	68	100	76	100	60	100
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	68	100	71	100	59	100
Primary Income Source	Aquaponics	0	0	21	28	2	3
	Other	68	100	53	72	56	97
	Total	68	100	74	100	58	100

Table 6.2. Experience, effort, system style, design, funding source, background setting, development stage and intent of scale-up by aquaponic stakeholders.

		Hobbyist		Producer		Educator	
		n	%	n	%	n	%
Years of Aquaponic Experience	< 1 year	25	24	29	19	16	14
	1-2 years	22	21	31	20	21	18
	3-5 years	35	34	38	25	30	26
	6-10 years	18	18	38	25	31	27
	11-20 years	3	3	15	10	10	9
	>20 years	0	0	4	3	9	8
	Total	103	100	155	100	117	100
Weekly Time Spent	0-10 hours	61	71	38	31	47	55
	11-20 hours	20	23	23	19	25	29
	21-30 hours	4	5	18	15	5	6
	31-40 hours	0	0	20	16	5	6
	41-60 hours	1	1	18	15	2	2
	> 60 hours	0	0	6	5	1	1
	Total	86	100	123	100	85	100
System Style	Coupled	85	92	114	84	75	85
	Decoupled	7	8	21	16	13	16
Background Setting	Rural	46	47	79	54	31	31
	Suburban	34	35	25	17	35	35
	Urban	17	17	37	26	34	34
	Industrial	1	1	4	3	1	1
	Total	98	100	145	100	101	100
Intent to Scale Up	Yes	37	44	97	76	39	53
	Unsure	34	40	21	16	26	35
	No	14	16	10	8	9	12

* n is the number of participants that responded when there was more than one selection option
** Composite scores are the sum of Likert rankings for knowledge in nine topic areas. Max score, 45

Table 6.3. Median and interquartile range (IQR)* of fish and plant production area, system volume, crop production output, and capital investment for aquaponic hobbyists, producers, and educators

Combined	Hobbyist	Producer	Educator
Area (ft^2)	112 (136)*† b	1,980 (6,140) a	320 (601) b
Volume (gal)	500 (900) b	4,098 (25,250) a	1,332 (3,269) ab
Production (lbs/yr)	35 (158) b	7,512 (34,498) a	365 (2,006) b
Investment ($USD)	1,000 (2,800) b	47,000 (188,000) a	2,800 (6,406) b
Investment/Area ($/$ft^2$)	10.2 (34.5) b	19.5 (54.1) a	12.5 (33.5) b
Investment/Volume ($/gal)	2.5 (5.0) b	5.2 (18.1) a	2.0 (3.4) b
Investment/Production ($/lb/yr)	22.2 (46.7) a	8.7 (14.5) b	4.8 (11.4) b
Plant/Fish Area Ratio (PFAR)	1.8 (2.1) b	4.8 (5.9) a	1.3 (1.9) b
Plant/Fish Production Ratio (PFPR)	0.9 (4.3) b	7.2 (15.0) a	2.8 (3.1) b
Fish/Plant Volume Ratio (FPVR)	1.2 (2.8)	0.8 (1.5)	1.5 (3.9)
Fish/Plant Investment Ratio (FPIR)	1.0 (1.0)	0.6 (0.8)	1.3 (3.3)

*IQR = Q_3-Q_1, indicating the spread of the response data.

†Letters denote significant differences ($\alpha = 0.05$) in Ln-transformed means using a One-way Analysis of Variance (ANOVA). Differences should be assessed within rows among the stakeholder group.

Table 6.4. Median and (IQR)* of fish and plant production area, system volume, crop production output, and capital investment for aquaponic hobbyists, producers, and educators.

		Fish			Plant		
Parameter	Unit	Hobbyist	Producer	Educator	Hobbyist	Producer	Educator
Area	ft^2	32 (84)*[†] b	565 (1925) a	100 (214) b	71 (151) y	2,036 (4,606) z	180 (252) y
Volume	gal	300 (663) b	2,000 (13,543) a	726.5 (1,200) b	200 (425) y	2,800 (15,140) z	330 (1,400) y
Production Output	lbs/yr	12 (28) b	1,000 (7,400) a	105 (596) b	10 (90) y	10,000 (38,100) z	242 (1,400) y
Investment	$USD	$1,000 ($1,288) b	$20,000 ($98,000) a	$2,400 ($4,200) b	$500 ($2,450) y	$19,000 ($118,928) z	$500 ($1,700) y
Volume/Area	gal/ft^2	7.9 (12.5)	7.5 (12.0)	8.3 (13.2)	4.5 (4.1) z	2.5 (4.8) y	3.8 (6.3) zy
Production/Area	$lbs/ft^2/yr$	0.9 (2.4) b	4.3 (13.0) a	2.0 (9.5) ab	0.8 (2.1) y	5.4 (9.5) z	2.2 (3.0) zy
Production/Volume	lbs/gal/yr	0.1 (0.3)	0.5 (0.9)	0.2 (0.6)	0.3 (0.5) y	2.6 (6.4) z	0.6 (1.1) y
Investment/Area	$\$/ft^2$	14.6 (47.2) b	23.6 (59.8) a	20.0 (78.5) a	8.5 (19.7) y	17.8 (44.3) z	8.1 (26.3) y
Investment/Volume	$/gal	3.0 (4.1)	3.6 (8.7)	2.0 (3.4)	2.5 (10.2) y	9.6 (21.7) z	3.0 (4.4) y
Investment/Production	$/lb/yr	30.0 (67.0) a	11.5 (17.3) b	7.3 (23.0) b	5.0 (24.2)	4.0 (8.9)	4.5 (7.5)

*IQR = Q_3-Q_1, indicating the spread of the response data.

[†]Letters denote significant differences ($\alpha = 0.05$) in Ln-transformed means using a One-way Analysis of Variance (ANOVA). Differences should be assessed within rows among the stakeholder groups and separately for fish and plant data.

Table 6.5. Correlations between production area, system volume, annual harvest, and investment for fish and plant portions of the aquaponic systems for all survey participants combined.

		1	2	3	4	5	6	7
1	Fish Area (ft^2)	--						
2	Fish Volume (gal)	0.809*	--					
3	Fish Production (lbs/yr)	0.796*	0.842*	--				
4	Fish Investment ($USD)	0.751*	0.776*	0.806*	--			
5	Plant Area (ft^2)	0.857*	0.800*	0.859*	0.697*	--		
6	Plant Volume (gal)	0.697*	0.813*	0.739*	0.613*	0.843*	--	
7	Plant Production (lbs/yr)	0.798*	0.775*	0.878*	0.740*	0.894*	0.809*	--
8	Plant Investment ($USD)	0.603*	0.617*	0.589*	0.761*	0.757*	0.706*	0.824*

Pearson's Correlation = r; * $p < 0.002$ Bonferroni adjustment for multiple correlations to minimize chances of Type I error, where $\alpha = 0.05/28 = 0.00178$.

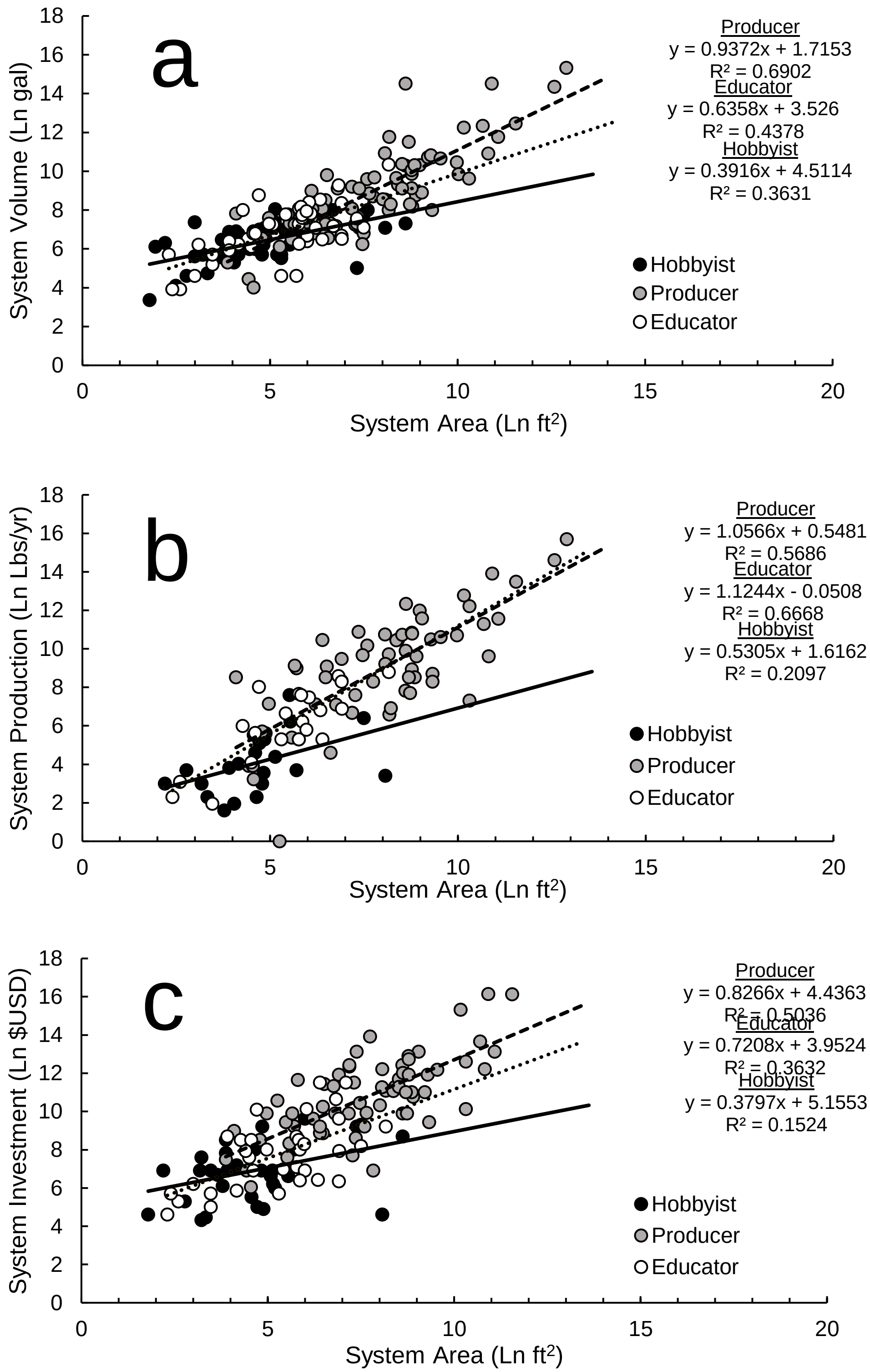

Figure 6.1. Scatter plot of combined fish and plant system Ln-area (ft^2) against a) combined system Ln-volume (gal), b) combined system production (lbs/yr), and c) combined system Ln-investment ($USD).

Chapter 7

Summary and Conclusions

Overview of Findings

Aquaponics presents opportunities for producing food, self-sufficiency, making money, and educating others in a scenario that is stimulating, interactive, and resources efficient (Love et al., 2014; Love et al. 2015c). Sustainable food is of interest to consumers, creating a premium market for those able to afford it (Short et al., 2017; Greenfeld et al., 2020a). Additionally, experiential learning with aquaponics has led to enhanced learning outcomes for STEM subjects (Hart et al., 2014), systems thinking (Junge et al., 2014), connecting food systems (Schneller et al., 2015), and improved attitudes and perceptions (Clayborn et al., 2017). Other learning benefits include increased academic performance, increased diet preference for healthy food, personal development, cooperation, and environmental awareness (Parmer et al., 2009; Morgan et al., 2009; Williams and Dixon, 2013; Genello et al., 2015).

Aquaponics is still a young industry, not yet becoming a major food production technique. Although it is viewed as a form of sustainable agriculture, it must meet requirements of social license, economic viability, and environmental impacts (Hansmann et al., 2012; Weeks, 2013). At present, aquaponics is granted social license because it appears to reduce environmental impacts of agriculture by efficiently utilizing water and nutrient inputs. However, investment and ongoing production costs simply make the product too expensive to compete with conventionally-grown crops, calling into question the economic viability of aquaponics and causing disillusionment among stakeholders (Turnsek et al., 2020). Additionally, knowledge level of newcomers tends to impede success in the early stages (Greenfeld et al., 2020b). Major stakeholder groups are hobbyists, producers, and educators, along with supporting groups like consultants, manufacturers, suppliers, retail merchants, researchers, regulators, processors, transporters, and more. These groups all have a vested interest in the success of aquaponics but have different needs and motivations. A needs assessment of the aquaponics industry was needed to project a successful way forward for growers. The goals of this study were to assess the current status of the aquaponic industry in the areas of 1) challenges experienced, 2) knowledge levels and needs, 3) informational resource usage, 4) production practices, and 5) production scale. The findings of this research are applicable to researchers, educators, policy makers, and other aquaponics industry supporting groups.

Study I. Challenges Experienced by Aquaponic Hobbyists, Producers, and Educators

We found that there are numerous challenges affecting aquaponic stakeholders. The challenge areas expressed by respondents serve as a need's assessment for areas of improvement.

Challenges were broadly categorized as:

1. Operations and management
2. Facilities, location, and system design
3. Knowledge and educational resources
4. Funding

5. Economic viability
6. Plant culture
7. Marketing and distribution
8. Fish culture
9. Human factors
10. Regulations and certifications

Additionally, regulatory challenge areas were summarized as:

1. Aquaculture/exotic species permitting
2. Zoning/construction/building permits
3. Certification/processing/food safety
4. Excessive bureaucracy/unclear policies
5. Institutional/school policy
6. Cost of permits/certifications
7. Effluent discharge

Recommendations for training opportunities were provided to assist researchers, educators, policy makers, and other supporting groups in facilitating the growth and success of local and regional aquaponic industries by nourishing educational efforts to address and deliver these needs. Difficulties with daily operations were most commonly mentioned, followed by factors related to the facility and obtaining relevant knowledge. The initial learning curve for aquaponics is steep because of all the integrated systems and skills required. We recommend the development of aquaponic informational resources and training opportunities to enhance the learning timeline of aquaponic enthusiasts. Holistic hands-on training workshops, perhaps led by Cooperative Extension programs, can instill participants with the confidence to perform daily activities and troubleshoot when issues arise. Training levels from single to multi-day workshops, as well as full undergraduate and graduate degree programs, and on-farm internships could be integrated to assist stakeholders at different levels of interest. Traditional delivery methods including trainings, workshops, meetings, as well as online instructional opportunities like webinars and distance education featuring reliable, quality research-based information sources may provide opportunities for participants to address challenges.

Study II. Knowledge Levels and Training Needs of Aquaponic Stakeholders

Struggles and failures of aquaponic growers call into question the viability of aquaponics as a commercial food production technology. Education of aquaponic stakeholders is necessary for the future success of the industry (Goddek et al., 2015). Given the considerable constraints facing aquaponic producers a comprehensive educational initiative is needed (Greenfeld et al., 2018; Konig et al., 2018; Palm et al., 2018). This study evaluated nine core aquaponic competencies, assessing the importance that growers place on them, their knowledge, and accessibility of quality information on those topics. Median respondent importance ratings were high, except for FRK and MFP, which hobbyists rated lowest. Similarly, knowledge of FRK and MFP were rated lower by hobbyists and educators. Quality information was generally rated as ‘moderately accessible’. Composite importance scores were lowest for hobbyists and highest for producers, indicating that producers took all topics more seriously. Likewise, composite knowledge scores were lower for hobbyists than producers and educators, indicating hobbyists had lower overall knowledge levels. The top needs for knowledge and information access based on the mean weighted discrepancy score (MWDS) for all groups were in the areas of FHD and PPD, whereas FS, WC, SM, and SD needs varied by group.

Recommendations for newcomers to aquaponics from the author's perspective would be to find a local, regional, or national training opportunity to attend. The opportunity to learn and network with like-minded individuals is the goal of professional associations (e.g. Aquaponics Association, World Aquaculture Society, etc.), and should be pursued by newcomers.

More Extension agents and educators should be trained in aquaponics to provide opportunities and informational resources in a variety of individual and group formats for participants to learn and network. Core competency areas evaluated in this study should be covered during trainings to varying degrees based on the target audience, their needs, and their knowledge level. Delivery methods such as lectures would impart knowledge, hands-on activities would provide confidence, site visits would give proof, and value stream exercises would give assurances that aquaponic enterprises can be viable. Each State's Land Grant University system should be available to help newcomers and train students in aquaponics to fill the roles of skilled workers, entrepreneurs, consultants, manufacturers, suppliers, teachers, researchers, and Extension agents.

Study III. Information Accessibility and Resource Usage by Aquaponic Stakeholders

Aquaponics has gained considerable attention in the past several years, bringing many new stakeholders into the fold. As with any new industry there are unknowns and misinformation presented from a variety of sources. Education of aquaponic stakeholders is necessary for the future success of the industry (Goddek et al., 2015). The initial learning curve for aquaponics is steep and training opportunities to enhance the learning timeline are sorely needed. It is critical to provide high quality information on appropriate topics in proper formats to promote success, and the industry could benefit from streamlining and standardization of practices and development of comprehensive guidelines for success (Greenfeld et al., 2018; Konig et al., 2018; Palm et al., 2018). This study provides a guide for prioritizing efforts to inform and support aquaponic growers from novice to advanced. Results indicated the most commonly used information sources overall were internet and videos, books and library, and classes and workshops. The most commonly desired information resource overall were other aquaponic growers, extension agents, classes/workshops, extension publications, and manufacturers/suppliers. The three most unused resources across all groups were friends and family, consultants, and social media.

There are a number of options for informational resources including digital, print, interactive, hands-on, and interpersonal formats, but matching this format to stakeholder needs is critical. Credible information in the wrong format in some cases could be mistakenly selected for use by the target end user and this is a situation that needs to be avoided.

Initial information delivery could focus on catching attention with short videos, then directing users to longer, more in-depth training videos. In-depth training methods could include lectures, hands-on activities, site visits, and value stream exercises to confer knowledge, confidence, perspective, and assurance that aquaponic enterprises can be viable. Additionally, more extension agents and educators should be trained in aquaponics to strengthen the aquaponic network throughout the US and world.

Study IV. System design and production practices of aquaponic stakeholders

As the aquaponic industry matures, it is prudent to track status, advances, and challenges facing hobbyists, producers, and educators. This study provides a comprehensive look at stakeholder systems and production practices. This study 1) assessed the current system design and production practices of the aquaponic industry; 2) evaluated these characteristics by user group; 3) identified trends for future development; and 4) needs for future growth.

Only 57% of systems were currently operational. Overall, aquaponic systems were largely homemade/do-it-yourself (DIY), especially for hobbyists (79%), while producers (30%) and educators (26%) often used a hybrid of DIY and commercially available (turn-key) technology. Funding sources were primarily personal funds (74%), government grants (18%), and private investor funds (14%). Coupled systems were the most popular overall (87%), which included recirculating aquaculture systems (70%) and either deep-water culture (71%) or media bed (64%) hydroponic units. Plant lighting sources included sunlight (79%), light emitting diode (43%), and fluorescent (22%). Water sources were typically municipal (47%) or wells (44%). Vegetable produce was the most common product sold, followed by training and education, food fish, and microgreens. Tilapia (*Cichlidae*) was the most commonly grown fish species across all groups (57%), followed by ornamental fish (e.g. koi and goldfish; *Cyprinidae*) (37%) with 16 other species being reported. The most commonly grown crops overall were lettuce (83%), leafy greens (81%), basil (73%), tomatoes (58%), peppers (44%), and herbs (43%) with many additional lesser-grown crops reported. It appears that the aquaponic industry scale is increasing in scale and production compared to earlier industry surveys. Diversification of fish and plant crops with emphasis on high value and low per unit production cost over time will be critical to profitability going forward.

Study V. System scale, production, and investment of aquaponic stakeholders

This study provided a comprehensive look at stakeholder systems scales, outputs, and inputs and provides some guidelines for system proportions, production potential and investment rates. An analysis of aquaponic system production parameters from real growers is needed to provide guidelines for newcomers. Fish and plant area, volume, annual production output and investment cost was greatest for producers. System sizes were different by background setting with rural systems generally being larger, more productive, and more expensive than urban systems, and suburban systems falling in between. The relationship between system area and volume, production output and investment were positive and linear when Ln-transformed. Producer systems generally had the greatest variance explained (R^2) in the regression model, and hobbyists had the least. The ratio of plant area to fish area and plant to fish production output were highest for producers, demonstrating that producers tend to focus on plant production. Investment per unit area and volume was highest for producers, while investment per unit production was greatest for hobbyists. Greater industry-combined production area, volume, and invested dollars compared to previous studies suggests the aquaponic industry is growing. Attention to system scale optimization with emphasis on high value and low per unit production cost will be critical to long-term profitability of the industry.

Opportunities and Proposed Solutions

Interrelated factors that affect the economic viability of an aquaponic business are location, consumer perceptions, economics/market, product sales price, system scale, quantity and cost of inputs (Quagrainie et al., 2017; Greenfeld et al., 2018). Reducing industry costs of aquaponics could be done by addressing 1) high initial capital requirements, 2) initial knowledge gaps of incoming producers, 3) legislative barriers to adoption, 4) compliance with organic certification standards, 5) marketing of aquaponic products, 6) monetizing the ecological benefits of aquaponics (Greenfeld et al., 2018). Certain projects can become viable with government interventions to subsidize the use of their products (e.g. tax benefits, grants, loans, purchase contracts, or direct subsidies), given that the benefit to society is great enough (Brewer, 2019). The range of viability outcomes varies across both economic and social/ecological spectrums, with the most viable operations providing profit and social/ecological benefits.

It is well known that the plant produce from an aquaponic system is the main revenue generator (Engle, 2015). Expanding aquaponic production beyond the greenhouse into field conditions could be a means of increasing production and cash receipts without high infrastructure cost (Pattillo et al., 2020). Fish production, especially tilapia, tends to operate at a financial loss, which provides challenges and opportunities for fish production (Engle, 2015). Sale of non-food fish, particularly high value ornamental species (e.g. koi), or longer-lived species that require long production periods (e.g. sturgeon) could be an opportunity for aquaponics. Alternative species that can be stocked at extremely high densities (e.g. *Clarias* catfish) may also provide opportunities to minimize fish production infrastructure and cost to optimize system profit (Baganz et al., 2020). Additionally, labor requirements can be quite high for aquaponics, making up 49% of the total operating budget (Quagrainie et al., 2017). Automation, data modeling and environmental sensing equipment will be a major focus of aquaponic innovation (Junge et al., 2017; Kyaw and Ng, 2017; Baganz et al., 2020).

Facility scale and location are important factors for incoming growers to consider. The location of a production facility has a lot to do with the cost of production – especially the cost of heating and cooling (Love et al., 2015b). If the system is located in a tropical climate, the need for controlled environments basically goes away, leaving a much larger profit margin in the budget (Tokunaga et al., 2015). Spreading out fixed costs over a greater number of sellable products is one of the most effective ways of decreasing production costs and increasing profitability (Xie and Rosentrater, 2015). Junge et al. (2017), suggested a minimum aquaponic facility footprint of 1,000 m^2 to cover operating expenses. Love et al. (2015a) suggested that the minimum income level to report profitability was approximately $50,000 USD annually. Xie and Rosentrater (2015) documented the effect of economies of scale on the breakeven price of tilapia and basil in an aquaponic system, with larger facilities being able to profit at lower per unit sales prices of basil. Quagrainie et al. (2017) had similar findings when analyzing the enterprise budgets of currently operating aquaponic farms at three different scales. Of course, there are 'sweet spots' in production that are more efficient and profitable than others. Baganz et al. (2020) described a decoupled system producing *Clarias* catfish and tomatoes in a greenhouse with supplemental income from surplus electricity sales from a gas-based combined heat and power unit with a payback period of 11.8 years on a 15-yr loan, or 8 years without loans.

The marketing and sales of aquaponic products are a major issue for producers (Greenfeld et al., 2018). Incorporation of agritourism, educational opportunities, and selling non-food products related to aquaponics is common practice to generate a profit, especially for smaller farms (Junge et al., 2017). As a farm gets larger, the need to sell more produce on a consistent basis becomes critical for cash flow and business solvency. This leads the producer to seek out more consistent markets, such as wholesale distributers, as opposed to retail markets like farmers markets and on-farm sales. The wholesale price will generally be much lower than the retail price, but the volume of produce that can be sold at that price is much higher. Additionally, regional urban/rural willingness to pay for aquaponic products can make the difference between profit and loss (Short et al., 2017). As business size increases, the need to produce at a lower cost becomes imperative to increase the revenue margin and generate a profit. Commercial aquaponics can work assuming the right price can be secured at a production volume that makes the business economically viable. The problem is knowing how big the business needs to be in order to maximize profitability. The research presented in these studies provide insight into methods and facilities used by other growers as a guide for newcomers.

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Appendix A. Aquaponic Industry Survey Tool

AUBURN UNIVERSITY

COLLEGE OF AGRICULTURE
SCHOOL OF FISHERIES, AQUACULTURE AND AQUATIC SCIENCES

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS IRB APPROVAL INFORMATION WITH CURRENT DATES HAS BEEN ADDED TO THIS DOCUMENT.)

INFORMATION LETTER
for a Research Study entitled
"A *Survey of Aquaponic Stakeholder Groups* "

You are invited to participate in a research study to define the current state of the aquaponics industry and inform support groups on the needs of the industry. This will help aquaponics support group identify industry needs and improve their services. The study is being conducted by D. Allen Pattillo, Ph.D. Student, under the direction of Terry R. Hanson, Professor and Co-Director of the Aquaculture and Fisheries Business Institute in the Auburn University School of Fisheries, Aquaculture, and Aquatic Sciences. You are invited to participate because you are an aquaponic industry stakeholder and are age 18 or older.

What will be involved if you participate? Your participation is completely voluntary. If you decide to participate in this research study, you will be asked to fill out an online survey about your involvement with the aquaponics industry. Your total time commitment will be approximately 20 minutes.

Are there any risks or discomforts? The risks associated with participating in this study are disclosure of your opinions, facility location, and some economic production data. To minimize these risks, we will keep your responses confidential and will only be reported in aggregate form.

Are there any benefits to yourself or others? If you participate in this study, you will be helping to facilitate the growth of the aquaponics industry. We/I cannot promise you that you will receive any direct benefits. Benefits to others may include better information for decision making, more training opportunities, and enhanced industry awareness.

Will you receive compensation for participating? There is no compensation for your participation, only our sincere appreciation.

Are there any costs? If you decide to participate, there is no cost to you.

INTERNATIONAL CENTER FOR AQUACULTURE AND AQUATIC ENVIRONMENTS

203 Swingle Hall
382 Mel Street
Auburn, AL 36849-5419

Telephone:
334-844-4786

auburn.edu/
www.auburn.edu/fish

The Auburn University Institutional Review Board has approved this Document for use from 12/10/2019 to --------------
Protocol # 19-544 EX 1912

AUBURN
UNIVERSITY

INTERNATIONAL CENTER FOR AQUACULTURE AND AQUATIC ENVIRONMENTS

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If you change your mind about participating, you can withdraw at any time by closing your browser window. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Once you've submitted anonymous data, it cannot be withdrawn since it will be unidentifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the School of Fisheries, Aquaculture, and Aquatic Sciences.

Any data obtained in connection with this study will remain anonymous. We will protect your privacy and the data you provide by using the secured Qualtrics software database, which prevents sharing outside of those conducting the survey. Information collected through your participation may be used to fulfill my Ph.D. dissertation requirements, published in a professional journal, and/or presented at a professional meeting.
The investigator reserves the right to terminate the survey depending on participation

If you have questions about this study, please contact Allen Pattillo at dap0005@auburn.edu or Terry Hanson at trh0008@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334) 844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION ABOVE, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, PLEASE CLICK ON THE LINK BELOW. YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

D. A. Pattillo ______ December 5, 2019
Investigator Date

Terrill R Hanson ______ December 5, 2019
Co-Investigator Date

The Auburn University Institutional Review Board has approved this document for use from December 10, 2019 to --------. Protocol **#19-544 EX 1912, Pattillo**

Survey Link: https://auburn.qualtrics.com/jfe/form/SV_0riUVSI68QHL40d

The Auburn University Institutional Review Board has approved this Document for use from 12/10/2019 to -------------
Protocol # 19-544 EX 1912

Aquaponics Survey - IRB Submission

Start of Block: Welcome

A Survey of Aquaponic Stakeholder Groups
focused questions for hobbyists, educators, and aquaponic producers

A Study By:
The School of Fisheries, Aquaculture, and Aquatic Sciences
Auburn University

Greetings from the Auburn University
School of Fisheries, Aquaculture, and Aquatic Sciences
The School of Fisheries, Aquaculture, and Aquatic Sciences (SFAAS) appreciates your participation in this study to generate a 'snapshot' of the status of the aquaponics industry. We recognize and appreciate your commitment to improving and advancing aquaponics.

This survey is intended for those age 18 and older, and the questions should take about 20 minutes to complete. Please fill out this survey to the best of your ability, although some questions may not apply to you. Your participation is voluntary, and your responses will be kept confidential and any data collected will be presented in aggregate form to ensure anonymity. If you have any questions or wish to provide additional feedback, please do so in the comments section at the end of this survey, or through email.

The information you share with us will be used to develop targeted research, teaching, and extension efforts to support the needs of the aquaponics industry.

Thank you for your participation. We look forward to hearing from you!

Sincerely,

D. Allen Pattillo, M.S.
Ph.D. Student - Aquaponic Economics
Auburn University
dap0005@auburn.edu

Dr. Terry Hanson, Ph.D.
Professor & Extension Specialist - Aquaculture Economics
Auburn University

Dr. David Cline, Ph.D.
Associate Extension Professor - Aquaculture
Auburn University

End of Block: Welcome

Start of Block: Introduction questions

How long have you been working with aquaponics?

- ○ < 1 year (1)
- ○ 1-2 years (2)
- ○ 3-5 years (3)
- ○ 6-10 years (4)
- ○ 11-20 years (7)
- ○ more than 20 years (8)

What first got you interested in aquaponics? *(check all that apply)*

- ☐ Fish (1)
- ☐ Plant (2)
- ☐ Healthy Food (3)
- ☐ Environmental Sustainability (4)
- ☐ Education /Teaching (5)
- ☐ Making Money (7)
- ☐ Need to know for my work (8)
- ☐ Self Sufficiency (9)
- ☐ Other (Please Explain) (6) ____________________

Which of the following categories best describes your interest in aquaponics?

- ○ Hobby/Home Gardening (1)
- ○ Producer (For-Profit Producer or Non-Profit Producers) (2)
- ○ Education (College/University, K-12, Extension, etc) (5)
- ○ Supporting Groups (Public agency, equipment supplier, community groups, etc.) (3)

Skip To: 7 If Which of the following categories best describes your interest in aquaponics? = Supporting Groups (Public agency, equipment supplier, community groups, etc.)

What is your current stage of aquaponic system development?

- ○ Researching/gathering information (4)
- ○ Planning and Design (1)
- ○ Facility Constructed (2)
- ○ Currently in Operation (3)
- ○ Not Applicable (6)

Please describe the construction style of your planned/current aquaponics system

- ○ Home made/Do-It-Yourself (DIY) (1)
- ○ Commercially available/Turn-Key (2)
- ○ Hybrid of DIY and Turn-Key (3)
- ○ Designed by a consultant (5)
- ○ Not Applicable (4)

Is your current/planned aquaponic system:

- ○ Coupled (fully recirculating between the fish and plant portions of the system) (1)
- ○ Decoupled (water flows from fish to plants and does not return to fish) (2)
- ○ Not sure (4)
- ○ Not Applicable (5)

What type of setting is your current/planned aquaponic system located in?

- ○ Urban (1)
- ○ Suburban (2)
- ○ Rural (3)
- ○ Industrial (4)

Please rate the ***importance*** of the following topics:

	Not important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
System Design (1)	○	○	○	○	○
System Construction (8)	○	○	○	○	○
System Maintenance (9)	○	○	○	○	○
Water Chemistry (2)	○	○	○	○	○
Fish Health/Disease (3)	○	○	○	○	○
Plant Pest/Disease/Nutrient Deficiencies (4)	○	○	○	○	○
Financial Record Keeping (5)	○	○	○	○	○
Marketing Food Products (6)	○	○	○	○	○
Food Safety (7)	○	○	○	○	○

Please rate ***your knowledge*** of the following topics:

	Not knowledgeable (1)	Slightly knowledgeable (2)	Moderately knowledgeable (3)	Very knowledgeable (4)	Extremely knowledgeable (5)
System Design (1)	○	○	○	○	○
System Construction (8)	○	○	○	○	○
System Maintenance (9)	○	○	○	○	○
Water Chemistry (2)	○	○	○	○	○
Fish Health/Disease (3)	○	○	○	○	○
Plant Pest/Disease/Nutrient Deficiencies (4)	○	○	○	○	○
Financial Record Keeping (5)	○	○	○	○	○
Marketing Food Products (6)	○	○	○	○	○
Food Safety (7)	○	○	○	○	○

Please rate the ***accessibility of quality information*** on the following topics:

	Not accessible (1)	Slightly accessible (2)	Moderately accessible (3)	Very accessible (4)	Extremely accessible (5)	Do not know (6)
System Design (1)	○	○	○	○	○	○
System Construction (8)	○	○	○	○	○	○
System Maintenance (9)	○	○	○	○	○	○
Water Chemistry (2)	○	○	○	○	○	○
Fish Health/Disease (3)	○	○	○	○	○	○
Plant Pest/Disease/Nutrient Deficiencies (4)	○	○	○	○	○	○
Financial Record Keeping (5)	○	○	○	○	○	○
Marketing Food Products (6)	○	○	○	○	○	○
Food Safety (7)	○	○	○	○	○	○

Where do you obtain information regarding aquaponics?

Select the items in the left column and drag them into the boxes on the right. Rank each category in terms of importance that you place on each information source, with 1 being most important.

I use this resource	I want to use this resource	I do not use this resource
______ Peer-Reviewed Scientific Journals (1)	______ Peer-Reviewed Scientific Journals (1)	______ Peer-Reviewed Scientific Journals (1)
______ Extension Agents (2)	______ Extension Agents (2)	______ Extension Agents (2)
______ Extension Publications (3)	______ Extension Publications (3)	______ Extension Publications (3)
______ Internet/Videos (4)	______ Internet/Videos (4)	______ Internet/Videos (4)
______ Social Media (5)	______ Social Media (5)	______ Social Media (5)
______ Friends/Family (6)	______ Friends/Family (6)	______ Friends/Family (6)
______ Books/Library (7)	______ Books/Library (7)	______ Books/Library (7)
______ Classes/Workshops (8)	______ Classes/Workshops (8)	______ Classes/Workshops (8)
______ Consultants (9)	______ Consultants (9)	______ Consultants (9)
______ Manufacturers/Suppliers (11)	______ Manufacturers/Suppliers (11)	______ Manufacturers/Suppliers (11)
______ Other Producers/Educators (10)	______ Other Producers/Educators (10)	______ Other Producers/Educators (10)

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

Please describe the scale of your current/planned aquaponic system.

Please enter the approximate values in the text boxes below.

For those using metric units, please convert to English units.
Unit Converter

Please report in US dollars.
Currency converter

	Fish Production (1)	Plant Production (1)

Production Area (square feet) (1)		
Water Volume (gallons) (2)		
Production (pounds/year) (3)		
Investment Cost ($USD) (5)		

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

What is the funding source for your current/planned aquaponic system?
(Check all that apply)

- ☐ Personal funds (1)
- ☐ Dealer financing (8)
- ☐ Investors/private funds (2)
- ☐ Bank/government loan (3)
- ☐ Private grant (5)
- ☐ Government grant (4)
- ☐ Credit card (6)
- ☐ Prefer not to disclose (7)

Do you sell any products relating to aquaponics?
(fish, plants, education/training, materials/supplies, etc.)

- ○ Yes (4)
- ○ No (5)

Display This Question:

If Do you sell any products relating to aquaponics? (fish, plants, education/training, materials/su... = Yes

Please indicate which of the following products or services you sell relating to aquaponics.
(check all that apply)

	(4)
Food Fish (10)	☐
Ornamental Fish (11)	☐
Vegetable Produce (12)	☐
Microgreens (5)	☐
Ornamental Plants (13)	☐
Materials/Supplies (2)	☐
Training/Education (1)	☐
Black Soldier Flies (8)	☐
Compost (3)	☐
Fish Emulsion (4)	☐
Composting Worms (6)	☐
Worm Castings (7)	☐
Other (please specify) (14)	☐

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

Do you plan to increase the scale of your aquaponics operation in the next 5 years?

- Yes (1)
- Maybe (2)
- No (3)
- Not Applicable (4)

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

Have you encountered any regulatory roadblocks regarding your aquaponics operation?

- Yes (1)
- No (2)
- Not Applicable (3)

Display This Question:

If Have you encountered any regulatory roadblocks regarding your aquaponics operation? = Yes

If yes, please specify the regulatory roadblocks that you have encountered.

____

____

____

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

Are there any permits or licenses that are required for your aquaponics operation?

- ◯ Yes (1)
- ◯ No (2)
- ◯ I don't know (3)
- ◯ Not Applicable (4)

Display This Question:

If Are there any permits or licenses that are required for your aquaponics operation? = Yes

If yes, please specify what permits or licenses that are required.

Please specify your top three challenges relating to aquaponics?

Write your response in the text boxes below.

- ○ Challenge #1 (1) ____
- ○ Challenge #2 (2) ____
- ○ Challenge #3 (3) ____

End of Block: Introduction questions

Start of Block: Hobbyist Questions

What sort of aquaponic training do you have? *(check all that apply)*

- ▢ Formal Training (University/College) (1)
- ▢ Informal Training (Workshop/Online) (2)
- ▢ Work Experience (Farm Training) (3)
- ▢ No Training (4)

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

How much time do you personally spend working with your system per week?

○ 0-10 hours (1)

○ 11-20 hours (2)

○ 21-30 hours (3)

○ 31-40 hours (4)

○ 41-60 hours (5)

○ > 60 hours (6)

End of Block: Hobbyist Questions

Start of Block: Fish Production

Fish Production

*The questions below should be answered based on the **fish production** in your aquaponics system.*

How long have you been producing fish?
Type the appropriate value in the box below.
Please round to nearest 0.5 year.

○ Number of Years Producing Fish (1) ____

What aquaculture techniques do you use? *(check all that apply)*

- ☐ Recirculating Aquaculture Systems (Clear Water) (1)
- ☐ Pond Systems (Green Water) (2)
- ☐ Biofloc Systems (Brown Water) (3)
- ☐ Flow-Through Systems (Raceways) (4)
- ☐ Cages (Net-Pens) (5)
- ☐ Other (Specify) (6) ____

Please tell us about your fish production system(s).
Select from the drop-down menu or fill in the text entry boxes.

For those using metric units, please convert to English units.
Unit Converter

	Fish Tank Size	Tank Shape	Tank Construction Material	Production Capacity
	Volume (gallons) (1)			Number of Tanks (1)
1 (1)		▼ Round (1 ... Other (3)	▼ Plastic (1 ... Other (7)	
2 (4)		▼ Round (1 ... Other (3)	▼ Plastic (1 ... Other (7)	
3 (2)		▼ Round (1 ... Other (3)	▼ Plastic (1 ... Other (7)	

Select the following aquaculture system components that you use in your aquaponic system.
(check all that apply)

- ▢ Clarifier/solids settler (1)
- ▢ Combination solids/biofilter (3)
- ▢ Dedicated mechanical filter (2)
- ▢ Dedicated biological filter (9)
- ▢ Protein skimmer (15)
- ▢ Aeration (4)
- ▢ Pure Oxygen (5)
- ▢ Ozone sterilization (6)
- ▢ Ultraviolet sterilization (7)
- ▢ Heater (8)
- ▢ Chiller (10)
- ▢ Water pump (11)
- ▢ Airlift (12)
- ▢ Environmental monitoring systems (13)
- ▢ Automated feeders (14)
- ▢ Backup generator (16)

What aquatic organisms do you grow? *(check all that apply)*

- ☐ Baitfish (minnows/shiners) (12)
- ☐ Barramundi/Jade Perch (27)
- ☐ Bluegill/Hybrid Sunfish (24)
- ☐ Catfish (13)
- ☐ Common/Grass Carp (14)
- ☐ Crayfish/Prawn (17)
- ☐ Largemouth Bass (25)
- ☐ Ornamental (Koi/Goldfish/aquarium fish) (2)
- ☐ Striped Bass/Hybrid (26)
- ☐ Tilapia (1)
- ☐ Trout/Salmon (5)
- ☐ Other (Specify) (23) ____

What are the key selection criteria that you use when choosing the *fish species* you raise?
(Check all that apply)

- ▢ Personal preferences (8)
- ▢ What the consumers want (including restaurants, groceries & individual buyers) (1)
- ▢ What grows well in my region (2)
- ▢ What is easy to grow in an aquaponics system (3)
- ▢ What is most profitable (4)
- ▢ Regional food preferences (5)
- ▢ Regulatory allowances (6)
- ▢ Other (please explain) (7) ____________________

What conditions do you grow your fish under? *(check all that apply)*

- ☐ Outdoors/open air (1)
- ☐ Shade house/canopy (2)
- ☐ High tunnel (no environmental control) (3)
- ☐ Greenhouse (with environmental control) (4)
- ☐ Indoors/Warehouse (5)
- ☐ Other (please specify) (6) ____

Please complete the table below, as best you can, by entering the proper values based on your *fish production for your <u>top 2 species.</u>*

Please convert to English units.
Unit Converter

	Species	Species
	1 (1)	2 (1)

Fish Species (common name) (1)		
Average Initial Length (inches) (2)		
Stocking Density (fish/100 gal) (3)		
Max Biomass (lbs/gal) (5)		
Average Harvest Weight (lbs) (7)		
Production Period from Stocking to Harvest (months) (9)		
Annual Feed Usage (lbs) (10)		
Survival (%) (11)		
Sales Price ($/lb) (12)		

What portion of the year do you produce your top 2 fish species?

Please enter the names of the fish in the boxes on the left and mark the boxes on the right for all seasons in which they are grown.

	Year Round (13)	Spring (1)	Summer (14)	Fall (15)	Winter (16)
Fish Species 1 (1)	▢	▢	▢	▢	▢
Fish Species 2 (2)	▢	▢	▢	▢	▢

End of Block: Fish Production

Start of Block: Plant Production

Plant Production

The following questions should be answered based on the ***plant production*** *in your aquaponic system.*

How long have you been producing plants?
Type the appropriate value in the box below.

Please round to nearest 0.5 year

○ Number of years producing plants (1) ____

What plant varieties do you grow? *(check all that apply)*

- ☐ Basil (12)
- ☐ Chives/Green Onion (11)
- ☐ Cucumber (17)
- ☐ Culinary Herbs (5)
- ☐ Eggplant (8)
- ☐ Flowers (21)
- ☐ Hemp/Cannabis (26)
- ☐ Pepper (10)
- ☐ Leafy greens (25)
- ☐ Lettuce (1)
- ☐ Microgreens (27)
- ☐ Root Crops (23)
- ☐ Strawberry (19)
- ☐ Tomato (6)
- ☐ Others (Please Specify) (24) ____

What are the key selection criteria that you use when choosing the *plant species* you raise?
(Check all that apply)

- ☐ Personal preferences (8)
- ☐ What the consumers want (including restaurants, groceries & individual buyers) (1)
- ☐ What grows well in my region (2)
- ☐ What is easy to grow in an aquaponics system (3)
- ☐ What is most profitable (4)
- ☐ Regional food preferences (5)
- ☐ Regulatory allowances (6)
- ☐ Other (please explain) (7) ____________________

Which of the following plant growing environments do you use?

- ☐ Outdoors/open air (1)
- ☐ Shade house/canopy (2)
- ☐ High tunnel (no environmental control) (3)
- ☐ Greenhouse (with environmental control) (4)
- ☐ Indoors/warehouse (5)
- ☐ Other (please specify) (6) ____________________

What type of lighting do you use? *(Check all that apply)*

- ☐ Sunlight (1)
- ☐ Fluorescent (4)
- ☐ High Pressure Sodium (HPS) (2)
- ☐ Incandescent (3)
- ☐ Induction (6)
- ☐ Light Emitting Diode (LED) (5)
- ☐ Other (please specify) (7) ____________________

Plant production parameters:
*Please complete, as best you can, the following table using **approximate average values** for the top 3 plant products produced on your farm.*

Please convert to English units.
Unit Converter

	Plant Species	Crop Duration	Annual Production	Sales Price
	(common name) (1)	(days) (1)	(lbs) (1)	($/lb) (1)
1 (1)				
2 (2)				
3 (3)				

Page Break

Based on the plant hardiness zone maps above, please select the zone where your facility is located.
Alaska is zone 3, Hawaii is zone 11, and Puerto Rico is Zone 12

Click here to search for your zone by zip code.

- ◯ Zone 1 (36)
- ◯ Zone 2 (35)
- ◯ Zone 3 (24)
- ◯ Zone 4 (25)
- ◯ Zone 5 (26)
- ◯ Zone 6 (27)
- ◯ Zone 7 (28)
- ◯ Zone 8 (29)
- ◯ Zone 9 (30)
- ◯ Zone 10 (31)
- ◯ Zone 11 (32)
- ◯ Zone 12 (33)
- ◯ Zone 13 (34)

Page Break

What plant production techniques do you use? *(check all that apply)*

- ☐ Deep Water Culture/Floating Rafts (1)
- ☐ Drip Irrigation/Dutch/Bato Buckets (2)
- ☐ Media Beds/Flood and Drain (5)
- ☐ Nutrient Film Technique (4)
- ☐ Vertical Towers (6)
- ☐ Wicking Beds (7)
- ☐ Other (Please specify) (3)

____

Please select the construction materials used for your plant production systems from the list below.
(check all that apply)

- ☐ Concrete (6)
- ☐ Fiberglass (8)
- ☐ Metal (2)
- ☐ Plastic (1)
- ☐ Polystyrene (Styrofoam) (4)
- ☐ PVC (11)
- ☐ Rubber/Plastic Liner (10)
- ☐ Sand/Gravel (5)
- ☐ Soil (9)
- ☐ Soilless Media (7)
- ☐ Wood (3)
- ☐ Other (12) ____

What portion of the year do you produce your top 3 plant species?

Please enter the names of the plants in the box on the left and mark the boxes on the right for the seasons in which they are grown.

	Year Round (13)	Spring (1)	Summer (25)	Fall (26)	Winter (27)
Plant Species 1 (1)	☐	☐	☐	☐	☐
Plant Species 2 (2)	☐	☐	☐	☐	☐
Plant Species 3 (3)	☐	☐	☐	☐	☐

End of Block: Plant Production

Start of Block: Food Safety Questions

Rate the following statements regarding your perceptions of different aspects of <u>food safety</u> in aquaponics.

	Strongly disagree (17)	Somewhat disagree (16)	Neither agree nor disagree (15)	Somewhat agree (14)	Strongly agree (13)
I have a solid understanding of food safety issues in aquaponic production (1)	○	○	○	○	○
I consider produce grown in aquaponics to be free of food-borne pathogens (2)	○	○	○	○	○
I consider fish grown in aquaponics to be free of food-borne pathogens (3)	○	○	○	○	○
I am familiar with the current regulations in the Food Safety Modernization Act (FSMA) for aquaponics production (4)	○	○	○	○	○

Display This Question:

If Which of the following categories best describes your interest in aquaponics? = Producer (For-Profit Producer or Non-Profit Producers)

Please respond to the following statements regarding food safety protocols used on your farm.

	Yes (1)	No (2)	I'm not familiar with this (6)	Prefer not to disclose (5)
My farm is Good Agriculture Practice (GAP) certified (1)	○	○	○	○
My farm currently has a Hazard Analysis and Critical Control Point (HACCP) plan (3)	○	○	○	○
My farm is currently Best Aquaculture Practices (BAP) certified. (4)	○	○	○	○

Display This Question:

If Which of the following categories best describes your interest in aquaponics? = Producer (For-Profit Producer or Non-Profit Producers)

What are your growing standards?
(Check all that apply)

- ▢ Certified USDA Organic (for plants) (1)
- ▢ Grow at/above USDA Organic Standards (Not Certified USDA Organic) (2)
- ▢ Conventional Growing (no certification standards) (3)
- ▢ Other (please explain) (4) ____
- ▢ Not Applicable (5)

Display This Question:

If Which of the following categories best describes your interest in aquaponics? = Producer (For-Profit Producer or Non-Profit Producers)

Please respond to the following statements regarding food safety protocols used on your farm.

	Yes (1)	No (2)	I'm not familiar with this (6)	Prefer not to disclose (5)
My farm currently has *Standard Operating Procedures* (SOP's) for harvesting **produce**. (5)	○	○	○	○
My farm currently has *Standard Operating Procedures* (SOP's) for harvesting **fish**. (2)	○	○	○	○

Display This Question:

If Which of the following categories best describes your interest in aquaponics? = Producer (For-Profit Producer or Non-Profit Producers)

Please respond to the following statements regarding food safety protocols used on your farm.

	Yes (1)	No (2)	I'm not familiar with this (6)	Prefer not to disclose (5)
My farm currently has Sanitation Standard Operating Procedures (SSOP's) for harvesting **fish**. (6)	○	○	○	○
My farm currently has Sanitation Standard Operating Procedures (SSOP's) for harvesting **produce**. (7)	○	○	○	○

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

The source of water for my aquaponics system is:
(check all that apply)

▢ City/Municipal Water (1)

▢ Well Water (2)

▢ Rain Water (3)

▢ Surface Water (pond, river, reservoir, etc.) (4)

▢ Other (please explain) (5)
____

▢ Not sure/Don't know (6)

Display This Question:

If Which of the following categories best describes your interest in aquaponics? = Producer (For-Profit Producer or Non-Profit Producers)

Would you like to participate in food safety research by submitting a sample of my aquaponics system water?
The results will be kept confidential and all supplies and postage are pre-paid.

If so, be sure to provide your contact information at the end of this survey.

○ Yes (1)

○ No (3)

End of Block: Food Safety Questions

Start of Block: Demographic Questions

Demographic Information
For statistical purposes, we need to ask you a few demographic questions. Please remember that information you provide is confidential!

Display This Question:

If Which of the following categories best describes your interest in aquaponics? != Supporting Groups (Public agency, equipment supplier, community groups, etc.)

Please provide the location of your aquaponic facility.

- ◯ Country (4) ____
- ◯ Postal (ZIP) code (3) ____

Is aquaponics your primary source of income?

- ◯ Yes (8)
- ◯ No (9)
- ◯ Prefer not to disclose (11)

Please select your employment status.

- ○ Employed full time (1)
- ○ Employed part time (2)
- ○ Unemployed looking for work (3)
- ○ Unemployed not looking for work (4)
- ○ Retired (5)
- ○ Student (6)
- ○ Disabled (7)
- ○ Prefer not to say (8)

Please select your ethnicity.

- ○ American Indian/Alaska Native (3)
- ○ Asian (4)
- ○ Black/African American (2)
- ○ Hispanic/Latino (8)
- ○ Native Hawaiian/Pacific Islander (5)
- ○ White/Caucasian (1)
- ○ Other (6)
- ○ Prefer not to say (7)

Please select your gender.

- ○ Male (1)
- ○ Female (2)
- ○ Prefer not to say (4)

Please select your education level completed.

- ○ Less than high school (1)
- ○ High school graduate or Equivalent (2)
- ○ Some college (3)
- ○ Vocational/Tech/Agricultural (9)
- ○ Associate degree (4)
- ○ Bachelors degree (5)
- ○ Masters (6)
- ○ Doctorate (7)
- ○ Prefer not to say (8)

Please select your age group.

- ◯ 18 - 24 (2)
- ◯ 25 - 34 (3)
- ◯ 35 - 44 (4)
- ◯ 45 - 54 (5)
- ◯ 55 - 64 (6)
- ◯ 65 - 74 (7)
- ◯ 75 - 84 (8)
- ◯ 85 or older (9)
- ◯ Prefer not to say (10)

End of Block: Demographic Questions

Start of Block: Ending questions

What advice would you give to people considering aquaponics?

____

____

____

____

____

If you are willing to answer additional follow-up questions and/or provide personal statements about the issues covered in this survey, please provide your contact information below so we can reach out to you.

Be sure to provide your information here if you would like to participate in the water testing option.

	(1)

Name of Person Completing this Survey: (1)	
Farm/Facility Name: (2)	
Location Address: (3)	
Location City/Town: (4)	
Location Zip Code: (5)	
Phone Number: (6)	
Email Address: (7)	

Please use the space below to provide additional comments related to this survey.

Thank you for completing this survey! Your responses are important to us and they will be kept confidential.

If you have questions or would like to be contacted about future aquaponics opportunities please send us an email at dap0005@auburn.edu

End of Block: Ending questions

Start of Block: Marketing Questions

Which of the following marketing methods do you use for your aquaponics operation?
Please rank them by importance.

Categorize the marketing methods (left column) into the boxes on the right and rank them by importance to your operation (1 = most important)

I use this currently	I want to use this	I do not use this
______ Email (5)	______ Email (5)	______ Email (5)
______ In person/point of sale (9)	______ In person/point of sale (9)	______ In person/point of sale (9)
______ No Advertising (10)	______ No Advertising (10)	______ No Advertising (10)
______ Print Media (Newspaper, magazine, fliers, etc.) (6)	______ Print Media (Newspaper, magazine, fliers, etc.) (6)	______ Print Media (Newspaper, magazine, fliers, etc.) (6)
______ Radio (4)	______ Radio (4)	______ Radio (4)
______ Signage (billboards, etc.) (11)	______ Signage (billboards, etc.) (11)	______ Signage (billboards, etc.) (11)
______ Search engine (ex. google) (8)	______ Search engine (ex. google) (8)	______ Search engine (ex. google) (8)
______ Social media (Facebook, Twitter, Instagram, etc.) (2)	______ Social media (Facebook, Twitter, Instagram, etc.) (2)	______ Social media (Facebook, Twitter, Instagram, etc.) (2)
______ Television (3)	______ Television (3)	______ Television (3)
______ Word of mouth (1)	______ Word of mouth (1)	______ Word of mouth (1)
______ Other (specify) (7)	______ Other (specify) (7)	______ Other (specify) (7)

What percentage of your *fish production* go to the following markets?

Write the approximate percentage of total fish production that goes to each respective market in the boxes on the right. The totals must equal 100 percent, indicated in the bottom box.

Farmer's Market : _______ (1)
Supermarket : _______ (2)
Restaurant : _______ (3)
Direct to Consumer : _______ (5)
Donations (Food Bank, Shelters, Family and Friends) : _______ (4)
Not Sold : _______ (6)
Total : _________

What percentage of your *plant production* go to the following markets?

Write the approximate percentage of total plant production that goes to each respective market in the boxes on the right. The totals must equal 100 percent, indicated in the bottom box.

Farmer's Market : _______ (1)
Supermarket : _______ (2)
Restaurant : _______ (3)
Direct to Consumer : _______ (5)
Donations (Food Bank, Shelters, Family and Friends) : _______ (4)
Not Sold : _______ (6)
Total : _________

What percentage of your farm's current products are sold within...
Enter your values based on the shortest distance.

Enter your values to the closest 5%. Totals must equal 100%.

Your town/city/county : _______ (1)
Your state : _______ (2)
Your region : _______ (3)
Nationally : _______ (4)
Internationally : _______ (5)
Not Sold : _______ (6)
Total : _________

Most of my product is sold within:

Select the shortest distance based on the majority (>50%) of your product sales.

For those using metric units, please convert to English units.
Unit Converter

- ○ 50 miles (1)
- ○ 100 miles (2)
- ○ 200 miles (3)
- ○ 500 miles (4)
- ○ 1,000 miles (5)
- ○ more than 1,000 miles (8)

How frequently do you make product deliveries per week?

- ○ 1/week (1)
- ○ 2-3/week (2)
- ○ 4-6/week (3)
- ○ 7-10/week (4)
- ○ more than 10/week (5)

End of Block: Marketing Questions

Start of Block: Commercial Business Questions

Aquaponics Economics

The following questions are based on the economics of your aquaponics production business. Providing this information will help create a better picture of the realities for aquaponic farmers.

Is your aquaponics operation...

- ◯ For-Profit (1)
- ◯ Not-for-Profit/Charity (2)

Is your aquaponics business currently operational?

- ◯ Yes (1)
- ◯ No (2)

What year did your aquaponics business first open?

____

Did you have any experience in aquaponics prior to starting your business?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Not Applicable (3)

What are your ***annual revenue*** from your aquaponic business?

Please report approximate amounts in US dollars.
Currency converter
Fish Production : ________ (1)
Plant Production : ________ (2)
Agritourism : ________ (7)
Constructing Systems for Others : ________ (9)
Consulting Services : ________ (6)
Education/Training : ________ (4)
Equipment/supplies/systems : ________ (5)
Other (please specify) : ________ (8)
Total : ________

What was your ***initial investment cost*** for your aquaponic business?

Please report approximate amounts in US dollars.
Currency converter

Buildings : ________ (2)
Construction Labor : ________ (4)
Fish System/Equipment : ________ (5)
Greenhouse/High Tunnel : ________ (1)
Land : ________ (3)
Plant System/Equipment : ________ (6)
Tools : ________ (8)
Vehicles : ________ (7)
Other (please specify) : ________ (9)
Total : ________

What are your ***annual operating costs*** for your aquaponic business?
Please report approximate amounts in US dollars.
Currency converter
Electricity : _______ (2)
Energy/Gas : _______ (3)
Fish Inputs : _______ (5)
Plant Inputs : _______ (6)
Interest on Loans : _______ (9)
Insurance : _______ (12)
Labor : _______ (1)
Management : _______ (11)
Repairs & Maintenance : _______ (7)
Taxes : _______ (8)
Water : _______ (4)
Other (please specify) : _______ (10)
Total : ________

What are your ***annual marketing costs*** for your aquaponic business?
Please report approximate amounts in US dollars.
Currency converter
Vendor Licensing Fees : _______ (2)
Vendor Fees (Farmers Markets, etc) : _______ (3)
Media/Outreach : _______ (5)
Transportation/Delivery Cost : _______ (9)
Other (please specify) : _______ (10)
Total : ________

Do you own or lease your property?

- ○ Own (1)
- ○ Lease (2)
- ○ Other (please specify) (3) ____

Do you consider your aquaponic business to be profitable?

- ○ Yes (1)
- ○ No (3)
- ○ Not Sure (2)
- ○ Prefer not to say (4)
- ○ Not Applicable (5)

Display This Question:

If Do you consider your aquaponic business to be profitable? = Yes

How long did it take for your aquaponic business to become profitable?

- ○ 0 to 0.5 years (1)
- ○ 0.5 to 1 years (2)
- ○ 1 to 3 years (3)
- ○ 3 to 5 years (4)
- ○ 5 to 10 years (5)
- ○ greater than 10 years (6)

There are many factors that affect the profitability of a business. **Which of these factors have the greatest positive or negative effect on the profitability of your aquaponic business? Select all that apply and rank them by importance.**

Drag the items from the column on the left and drop them in the boxes on the right. Organize them based on importance (1 = most important).

Positive Impact	Negative Impact
______ Production scale (1)	______ Production scale (1)
______ Proximity to market (2)	______ Proximity to market (2)
______ Production methods (4)	______ Production methods (4)
______ Sustainability (14)	______ Sustainability (14)
______ Political support (16)	______ Political support (16)
______ Regulations (12)	______ Regulations (12)
______ Products grown (5)	______ Products grown (5)
______ Sales Price (18)	______ Sales Price (18)
______ Product quality (17)	______ Product quality (17)
______ Cost of production (7)	______ Cost of production (7)
______ Local climatic conditions (8)	______ Local climatic conditions (8)
______ Access to inputs (9)	______ Access to inputs (9)
______ Other (please specify) (10)	______ Other (please specify) (10)

How many people work at your farm?

Full Time : _______ (1)
Part Time : _______ (3)
Seasonal : _______ (9)
Unpaid/Family/Volunteer : _______ (8)
Total : _________

Do you pay for employee benefits (i.e. health insurance, retirement, etc.)?

○ Yes, for all employees (1)

○ Yes, for full-time employees only (2)

○ No (3)

Do you currently have a farm insurance policy for your aquaponics business?

○ Yes (40)

○ No (41)

Please organize the following skills in order of importance to your aquaponics operation.

Drag the following statements to rank in descending order where 1 is most important.

______ Computer Software (14)
______ Financial Record Keeping (13)
______ Fish Care (11)
______ Fish Spawning (2)
______ Good Work Ethic (9)
______ Grace Under Pressure (17)
______ Maintenance (7)
______ Plant Care (12)
______ Punctuality (8)
______ Pest Management (3)
______ Water Quality (16)
______ Marketing/Advertising (18)

End of Block: Commercial Business Questions

Start of Block: Educator Questions

Please provide your years of teaching experience.
Enter appropriate value in the boxes below.
Please round your answer to the nearest 0.5 years.

○ Years of teaching experience (1) ____

○ Years of teaching with aquaponics (2) ____

What group of students do you work with? *(check all that apply)*

- ☐ Pre-Kindergarten (1)
- ☐ Kindergarten - 2nd grade (2)
- ☐ 3rd - 5th grade (3)
- ☐ 6th - 8th grade (4)
- ☐ 9th - 12th grade (5)
- ☐ Vocational/ Agriculture (6)
- ☐ Junior College (7)
- ☐ 4-yr College (8)
- ☐ Graduate Students (9)
- ☐ Adults (10)

Cumulatively, approximately how many students have you taught using aquaponics as a teaching tool?

____

How many of your students have continued with aquaponics after leaving your class?
Please enter the number of individuals in the fields below:
College/University : _______ (1)
Home Use/Hobby : _______ (7)
Aquaponic Technicians : _______ (5)
Business Owners/Farmers : _______ (4)
Other (please specify) : _______ (6)
Total : ________

Please rate the **availability of teaching materials** related to:

	Poor (1)	Below Average (2)	Average (3)	Above Average (4)	Excellent (5)
System Design (1)	○	○	○	○	○
System Construction (8)	○	○	○	○	○
System Maintenance (9)	○	○	○	○	○
Water Chemistry (2)	○	○	○	○	○
Fish Health/Disease (3)	○	○	○	○	○
Plant Pest/Disease/Nutrient Deficiencies (4)	○	○	○	○	○
Financial Record Keeping (5)	○	○	○	○	○
Marketing Food Products (6)	○	○	○	○	○
Food Safety (7)	○	○	○	○	○

Please rate the quality of materials currently available to teach:

	Poor (1)	Below Average (2)	Average (3)	Above Average (4)	Excellent (5)
System Design (1)	○	○	○	○	○
System Construction (8)	○	○	○	○	○
System Maintenance (9)	○	○	○	○	○
Water Chemistry (2)	○	○	○	○	○
Fish Health/Disease (3)	○	○	○	○	○
Plant Pest/Disease/Nutrient Deficiencies (4)	○	○	○	○	○
Financial Record Keeping (5)	○	○	○	○	○
Marketing Food Products (6)	○	○	○	○	○
Food Safety (7)	○	○	○	○	○

Which of the following best represents your teaching responsibilities?
(check all that apply)

- ☐ Agriculture Education (Agriculture, Horticulture, Aquaculture, Livestock, etc.) (1)
- ☐ Science (Biology, Chemistry, Physics, Physical Science, etc.) (2)
- ☐ Vocational (Welding, Construction, Shop, etc.) (3)
- ☐ Technology (Engineering, Computers Science, etc.) (4)
- ☐ Math (Algebra, Geometry, Statistics, etc.) (5)
- ☐ Other (please explain) (6) ____

How useful is aquaponics to teach these subjects?

	Not Useful (1)	Somewhat Useful (2)	Moderately Useful (3)	Very Useful (4)	Extremely Useful (5)
Agriculture (6)	○	○	○	○	○
Biology (3)	○	○	○	○	○
Business (5)	○	○	○	○	○
Chemistry (2)	○	○	○	○	○
English (20)	○	○	○	○	○
Ecology (22)	○	○	○	○	○
Food Safety (21)	○	○	○	○	○
Math (1)	○	○	○	○	○
Physics (4)	○	○	○	○	○
Social Studies (23)	○	○	○	○	○

How useful is aquaponics for teaching these skills?

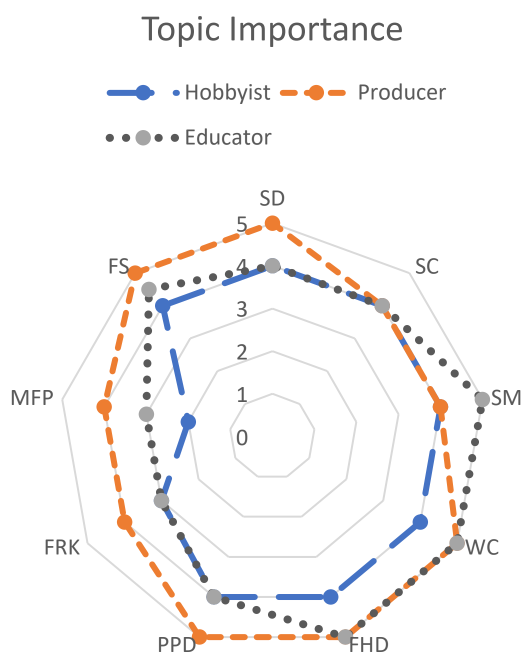
	Not useful (1)	Somewhat Useful (2)	Moderately Useful (3)	Very Useful (4)	Extremely Useful (5)
Collaborative Learning (2)	○	○	○	○	○
Creative Problem Solving (1)	○	○	○	○	○
Leadership (3)	○	○	○	○	○
Presentation Skills (5)	○	○	○	○	○
Responsibility (4)	○	○	○	○	○

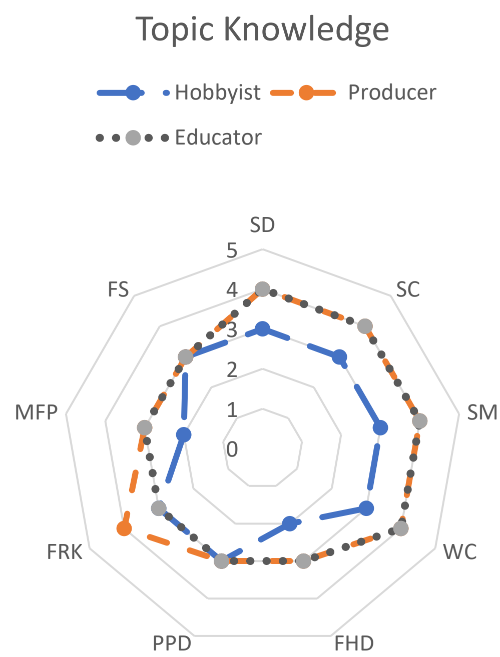
Please respond to the following statements by selecting the most appropriate option below:

	Strongly disagree (20)	Somewhat disagree (21)	Neither agree nor disagree (22)	Somewhat agree (23)	Strongly agree (24)
My students are academically engaged when I teach using aquaponics (1)	○	○	○	○	○
My fellow teachers are interested in aquaponics as a teaching tool (2)	○	○	○	○	○
My administrator is supportive of aquaponics in the classroom (4)	○	○	○	○	○
I have all the financial resources I need to support the use of aquaponics in the classroom (3)	○	○	○	○	○

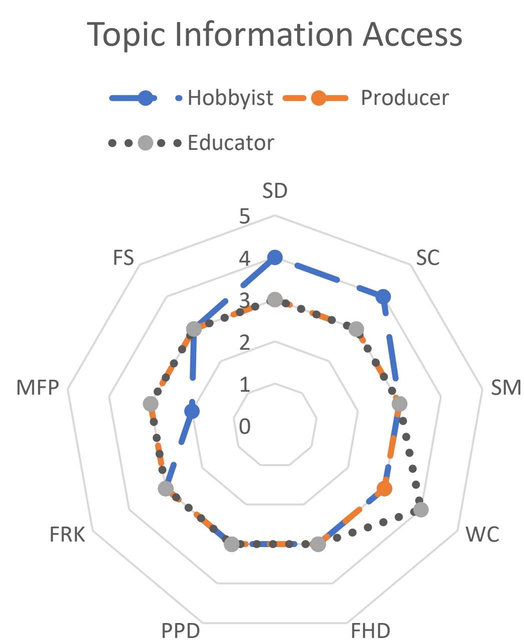
End of Block: Educator Questions

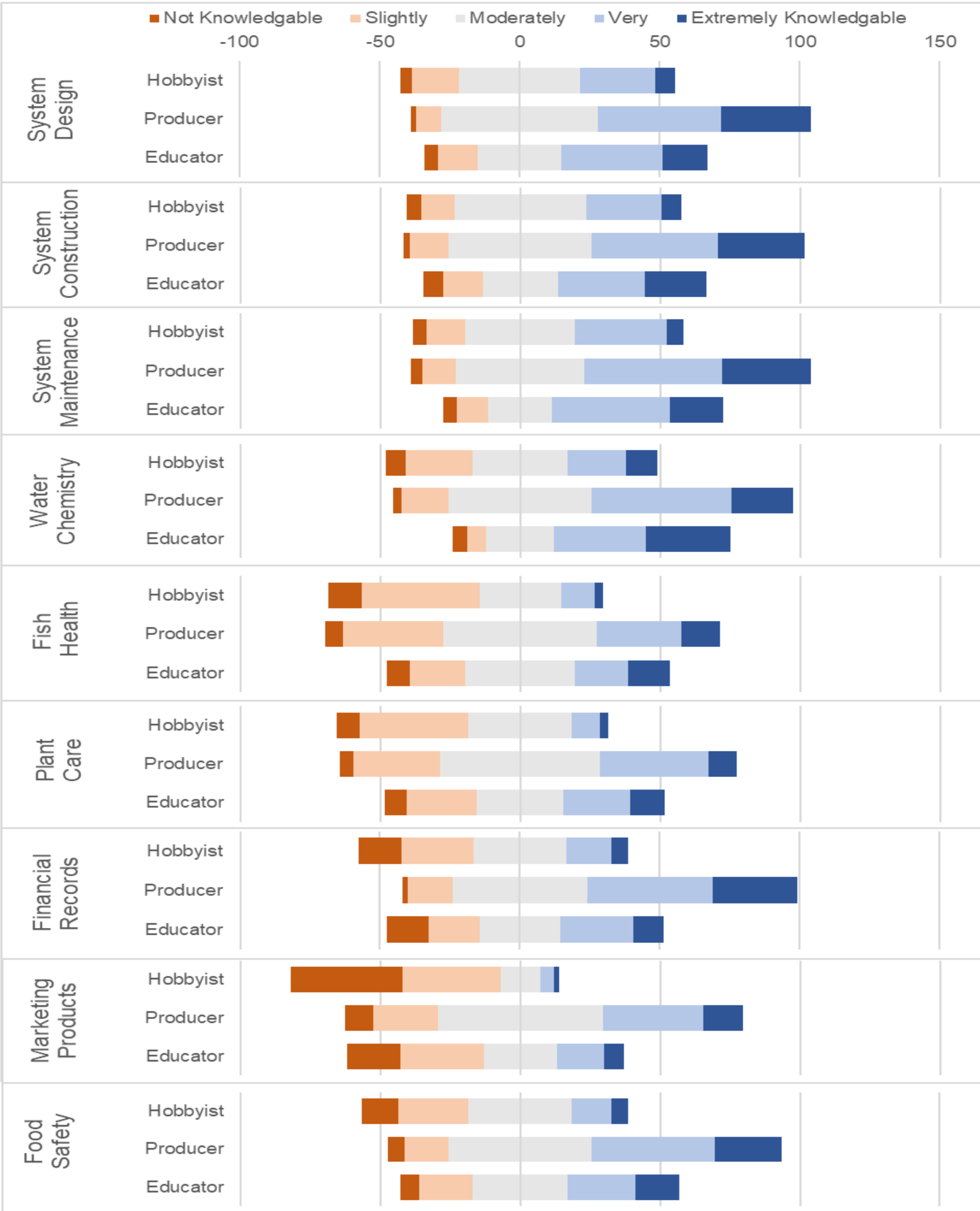
Appendix B. Core Competency Ratings



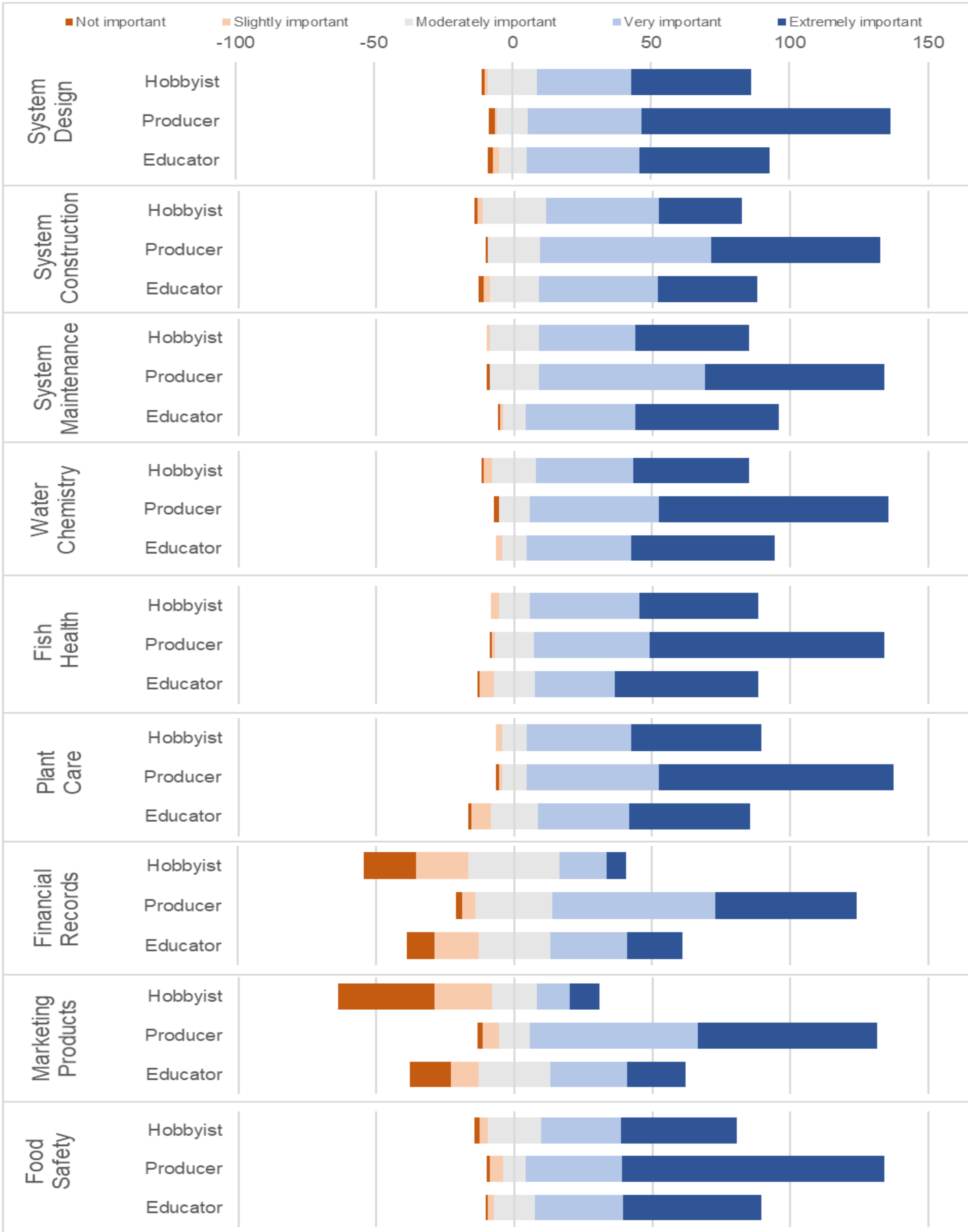


Appendix B1. Median scores for aquaponic hobbyists, producers, and educators for perceived importance, knowledge, and access to quality information in the areas of system design (SD), system construction (SC), system maintenance (SM), water chemistry (WC), fish health and disease (FHD), plant pest, disease, and nutrient deficiencies (PPD), financial record keeping (FRK), marketing food products (MFP), and i) food safety (FS). Scale values were: 1 = not, 2 = slightly, 3 = moderately, 4 = very, and 5 = extremely, for knowledge, importance, and accessibility of information.

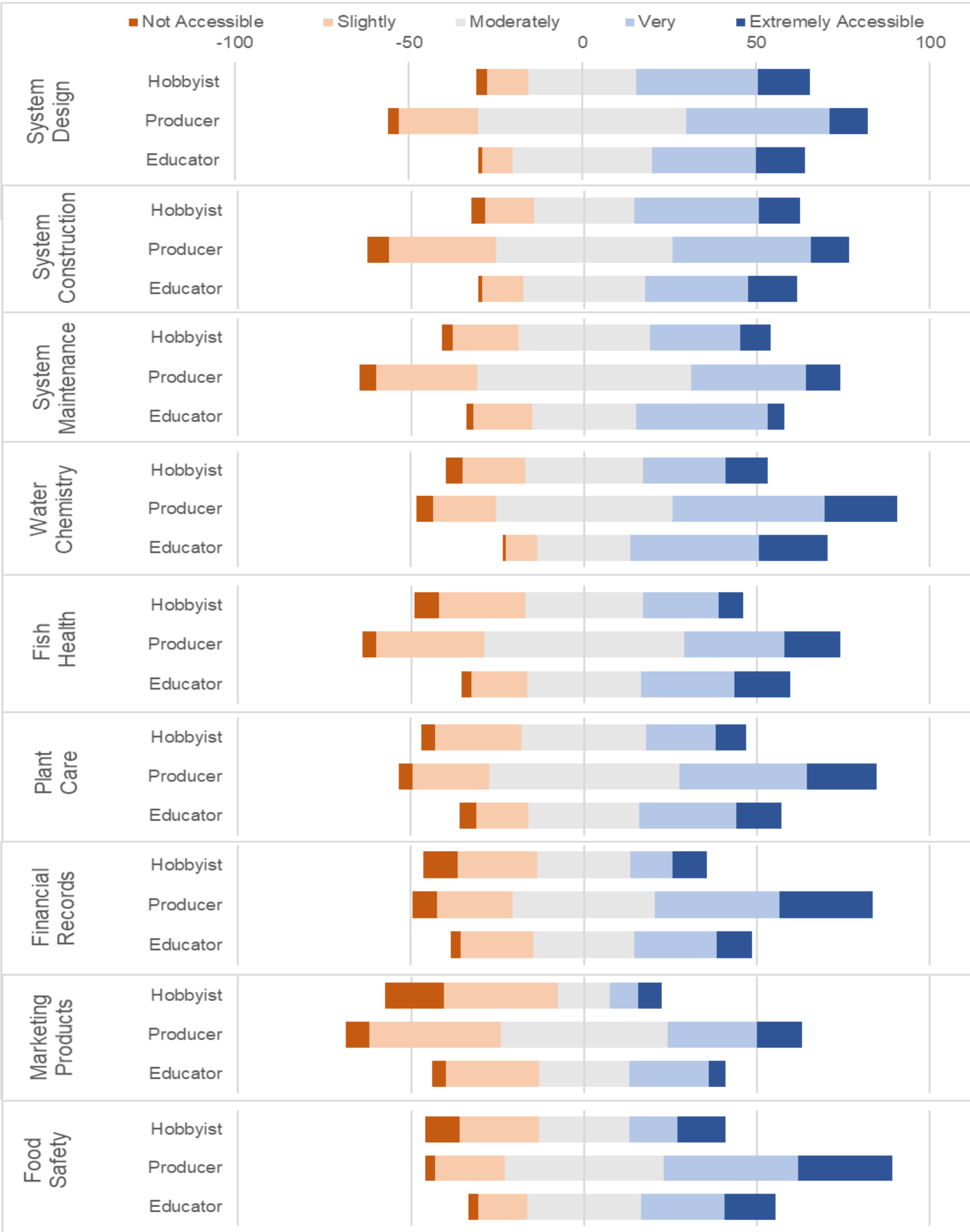




Appendix B2. Perceived knowledge of information topics relating to aquaponics by hobbyists, producers, and educators.

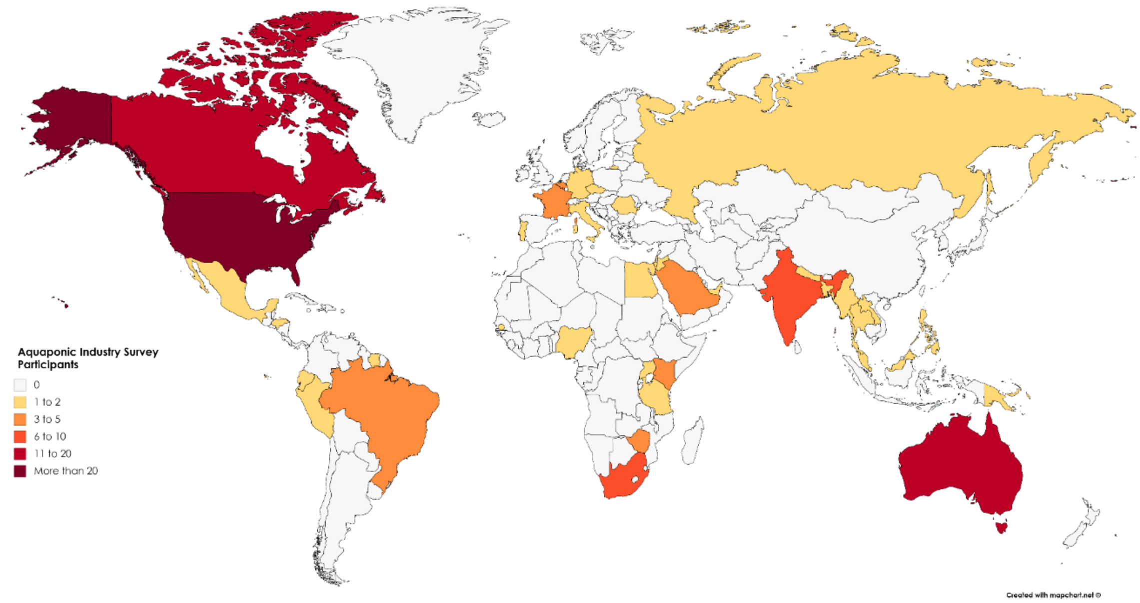


Appendix B3. Perceived importance information topics relating to aquaponics by hobbyists, producers, and educators.



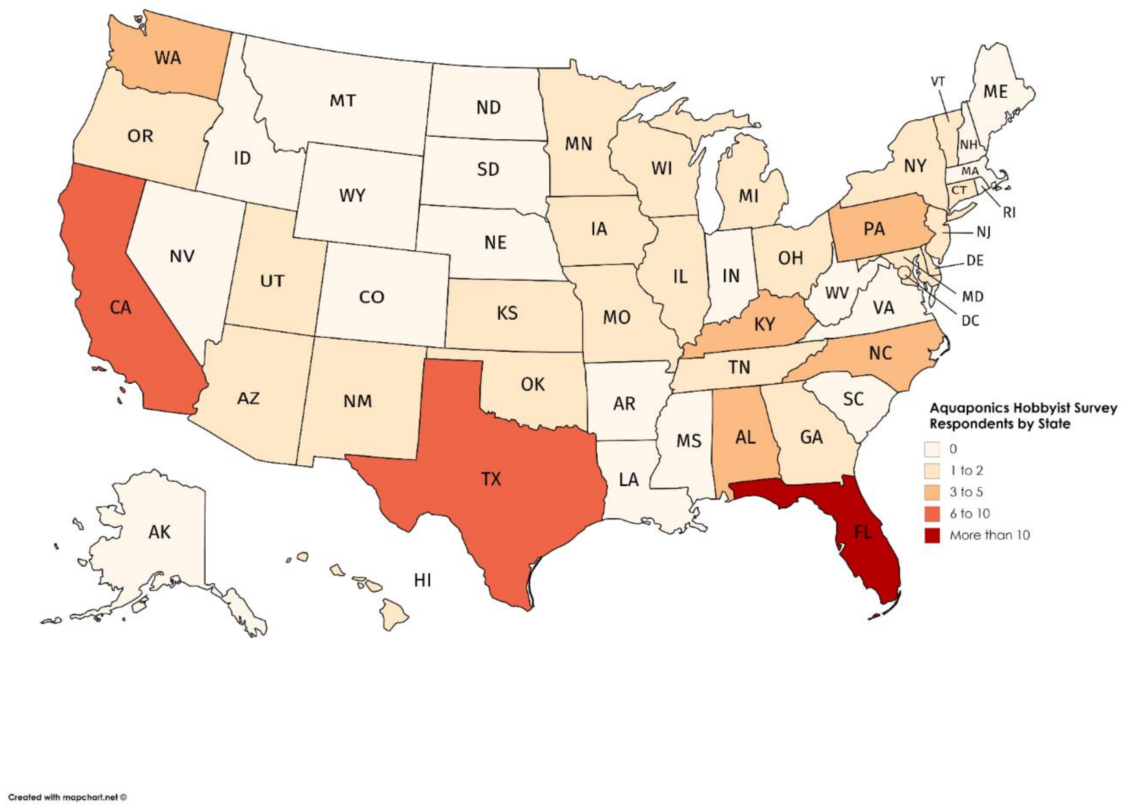
Appendix B4. Perceived accessibility of quality information relating to aquaponics by hobbyists, producers, and educators.

Appendix C. Survey Respondent Density Map

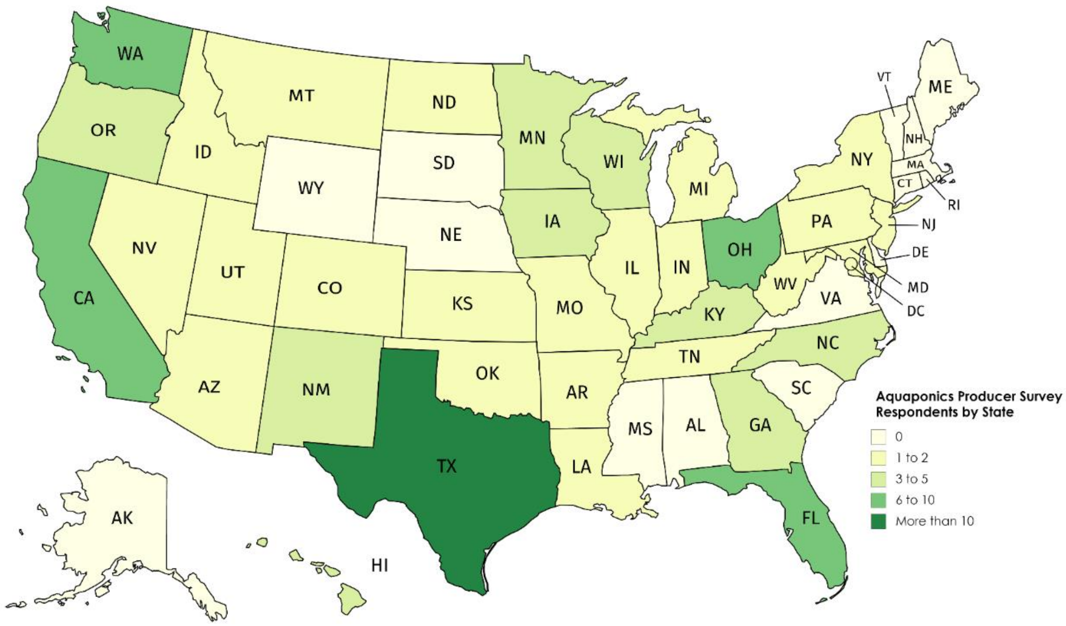


Appendix C1. Global distribution of aquaponic survey participants.

Appendix C2. Density map of U.S. hobbyists who participated in the aquaponic industry survey.



Appendix C3. Density map of U.S. producers who participated in the aquaponic industry survey.



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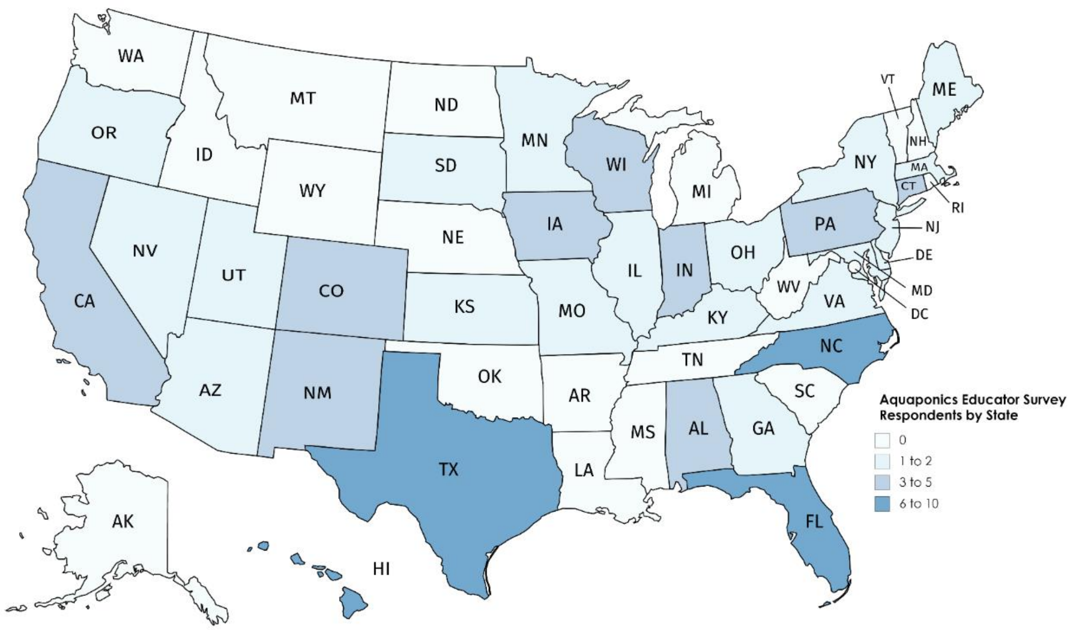
Appendix C3. Density map of U.S. educators who participated in the aquaponic industry survey.



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