

Fish in the Classroom: A Survey of the Use of Aquaponics in Education

Laura Genello*

Johns Hopkins University, USA

Corresponding author: lgenell1@jhu.edu

Jillian P. Fry

Johns Hopkins University, USA

J. Adam Frederick

University of Maryland College Park, USA

Ximin Li

Johns Hopkins University, USA

David C. Love

Johns Hopkins University, USA

•Received 10 June 2015

•Revised 17 July 2015

•Accepted 25 July 2015

School gardens and demonstration farms are exciting avenues for experiential learning in education. Aquaponics, the combination of aquaculture and hydroponics, is an attractive educational tool because systems are self-contained ecosystems that allow teachers and students to explore a wide range of science, technology, engineering, and mathematics (STEM) topics. The aim of this study was to characterize the use of aquaponics in education in the United States (US) using an online survey. One hundred respondents who completed the survey were engaged with aquaponics education and met the inclusion criteria for the study. Thirty-six percent of respondents worked for primary and secondary schools, 53% represented colleges or universities, and 11% worked for vocational or trade schools. Respondents reported the subjects taught, target audiences, number of participating students or visitors, and the resources and funding used by their organizations. Respondents used aquaponics to engage students in a variety of STEM subjects. In total, respondents and their institutions engaged an estimated range of 12,320 to 50,250 participants per year in aquaponics education. The typical school invested \$1,000 to \$4,999 US dollars (USD) in their aquaponics facility during the previous year, with a combined total of \$1.4 to \$6.6 million USD invested by all academic institutions. Aquaponics is an emerging educational tool, and there is a need for continued collaboration, technical support, and training for educators from universities and aquaculture education and research centers in the US and other countries.

Keywords: aquaponics, school gardens, garden-based learning, aquaculture, hydroponics

INTRODUCTION

As the sustainable agriculture movement has expanded, so has interest in using school gardens and demonstration farms for experiential learning in education (Williams & Dixon, 2013; Mazurkewicz, Harder, & Roberts, 2012). Williams and Dixon (2013) reason that garden-based learning aligns with two recent trends of public interest: growing awareness of the need for improved health, particularly children's health, and the increasing awareness of the importance of children spending time in nature. Experiential learning through gardening has been documented to have a wide range of positive impacts on students, including direct academic outcomes such as improved performance in science, math, or language arts, and non-academic outcomes such as increased dietary preference for fruits and vegetables, personal development, cooperation, and environmental awareness (Parmer, Salisbury-Glennon, Shannon, & Struempfer, 2009; Morgan, Hamilton, Bentley, & Myrie, 2009; Williams & Dixon, 2013).

In addition to soil-based gardening, other methods of agriculture are increasingly incorporated into educational curricula and activities, including aquaculture, hydroponics and aquaponics (Frederick 2005). Aquaculture systems, in which aquatic plants and/or animals are raised, can be effective tools for providing students with new environments for hands-on learning (Caldwell 1998; Frederick 2005; Wigenbach, Gartin, & Lawrence, 1999). Initially, aquaculture education was focused on traditional agriculture and vocational schools in order to produce a qualified workforce for the aquaculture industry; however, increasingly educators in secondary schools are taking an interest in incorporating aquaculture into their programming as a vehicle to teach science, math, and other topics (Frederick 2005), and Soares, Buttner and Leavitt (2001) document a variety of existing aquaculture curricula for educators. In fact, at least one program, the Maryland Sea Grant Aquaculture in Action program in the United States, has been developed to offer training and support for teachers running recirculating aquaculture systems in their classrooms for use as a living laboratory for student research projects (Maryland Sea Grant, 2014).

Aquaponics is a form of aquaculture, in which hydroponic plant grow beds are joined with aquaculture tanks. In aquaponics systems, fish waste is used to fertilize plants, and bacteria and plants remove nutrients, filtering the water for the fish. Aquaponics systems recycle water while converting the fish waste into a resource, and provide an avenue for educators to discuss ecosystem functions, sustainability, resource conservation, agriculture, and healthy food production. In a survey of 10 educators using aquaponics systems in their classrooms, Hart, Webb and Danylchuk (2013) found that educators were attracted to aquaponics because it offers hands-on learning, flexibility, integration of fun and science, use of technology, and address science, technology, engineering, and math (STEM) and food concepts. Moreover, operation of an aquaponics system incorporates knowledge from a variety of subjects including agriculture, biology, engineering, nutrition, chemistry, and technology providing educations with ample opportunity to incorporate aquaponics systems into their lesson plans across a variety of disciplines. Aquaponics also provides stimulating material and project-based learning opportunities for students and teachers (Wardlow, Johnson, Mueller, & Hilgenberg, 2002).

While the use and impact of soil-based school gardens has been frequently documented in the literature, existing literature on the use of aquaponics in education is limited and primarily focuses on documenting case studies or presenting student/teacher feedback. Nelson (2007) documents several examples of educators using aquaponics systems as a teaching tool for STEM education, a living laboratory for student research projects, or a site for job training and hands-on agricultural experience (Nelson, 2007). In an article in *Tech Directions*, technology

teacher Erik Johansen reported on his personal experience using an aquaponics system to successfully integrate biotechnology components into his curriculum. The aquaponics system allowed his students to work on creative engineering projects, such as creating an automated fish feeder using legos, or modifying a toilet-bowl fill valve to regulate water flow (Johanson, 2009). In another example, Wardlow, Johnson, Mueller, and Hilgenberg (2002) documented the “Aquaponics in the Classroom” program, run by the University of Arkansas, in which teachers were loaned prefabricated aquaponics systems for their classrooms for use as a teaching aid in STEM education. Aquaponics systems have also been used in higher education. A team of students and professors in the Department of Environmental Science at Allegheny College developed an aquaponics system as a platform for community engagement and student research projects (Eatmon, Szymecki, & Varrato, 2012).

While examples of aquaponics in education are easy to find, the scope and extent of aquaponics in education has not been well-documented. The aim of this study was to characterize the use of aquaponics in schools in the United States, and the findings could be applicable to other countries. Specifically, we report: the demographic profile of survey respondents practicing aquaponics-based education; the characteristics of classroom systems, the target audiences of those education activities; the education subjects taught using aquaponics; the number of participants; the knowledge of system operators, and the resources and funding used by organizations. We hope that these findings can help create a foundation for future research on aquaponics education and inform educators interested in integrating aquaponics systems into their curriculums. As the aquaponics industry gains momentum, interest in aquaponics in education is likely to increase. Understanding the extent of the practice currently is an important first step in understanding the overall effectiveness of this new education technology.

METHODS

Survey

An online survey questionnaire was developed and implemented as described by Love (2014). Survey questions were drafted and pretested with a group of 10 aquaponics practitioners. The final survey was distributed using Qualtrics (Provo, Utah), a web-based survey platform. Because the target population has not been previously well-defined, the survey was distributed using a chain sampling method (i.e. referral or snowball sampling) with the help of eighteen partner organizations who distributed the survey to their subscribers and members through email lists, direct email, social media posts, and online newsletters. The survey was also emailed to 365 potential respondents whose contact information was obtained at one of two aquaponics conferences in 2013 (The Aquaponics Association Conference in Tuscon, AZ and the International Aquaponics Conference in Stevens Point, WI). The survey codebook, which contains a complete list of survey questions, is provided in the supplement to Love (2014). The methodology was reviewed by the Johns Hopkins University Institutional Review Board (IRB No: 00005088).

The survey was open between June 25, 2013 and October 1, 2013, and 1084 complete responses were collected during this period. The inclusion criteria for the present analysis was as follows: any respondent who was 18 years of age or over, can read English, had operated and maintained an aquaponics system within the previous 12 month period, had taught aquaponics (*e.g.*, host tours, classes, courses, lectures, or workshops) within the previous 12 months, and represented an educational institution (primary or secondary school, colleges, universities, or

vocational schools). Respondents were asked to submit a maximum of one response per organization. One hundred respondents met the inclusion criteria.

Data analysis

Data from the survey software (Qualtrics, Provo, UT) were exported and analyzed in Excel (Microsoft, Redmond, WA), STATA (StataCorp LP, College Station, TX), SPSS (IBM, Armonk, NY), and Prism (v5, GraphPad, La Jolla, CA).

RESULTS

Demographics

Just over half of all respondents (53%) represented colleges or universities (Table 1). Thirty-six percent worked for primary or secondary schools and 11% worked for vocational or technical schools. Among respondents, 77% were male, 20% were female, and 3% did not specify a gender. The mean age of respondents was 46 years old. Forty six percent of respondents had a graduate degree, and 45% had a college degree or had taken some college classes. Most respondents (54%) had less than 3 years prior experience practicing aquaponics, with only 6% of respondents having greater than 5 years prior experience. Ninety two percent of all respondents lived in the United States representing 35 different states; one respondent each lived in Australia, Malaysia, and Canada. Three respondents did not report a location.

Table 1. Demographics of survey respondents engaged in education and outreach.

Demographics	Number of respondents (%)		
	K-12 Primary and Secondary School	2-year or 4-year College or University or Graduate School	Vocational or Trade School or Training Center
Overall	36	53	11
Gender			
Male	28 (78)	43 (81)	6 (55)
Female	7 (19)	10 (19)	3 (27)
Not specified	1 (3)	-	2 (18)
Age, yr			
18-29	5 (14)	12 (23)	1 (9)
30-39	5(14)	7 (13)	1 (9)
40-49	7 (19)	14 (26)	1 (9)
50-59	15 (42)	14 (26)	4 (36)
60-69	4 (11)	6 (11)	3 (27)
70+	-	-	1 (9)
Education			
Graduate degree	18 (50)	28 (53)	-
College degree or college classes	17 (47)	19 (36)	9 (90)
High school, GED, or some high school	1 (3)	-	1 (10)
Country			
United States	32 (89)	52 (98)	9 (90)
Not reported	3 (8)	-	-
Other country	1(3) Australia	1(2) Malaysia	1 (10) Canada

Aquaponics experience, yr			
<1	6 (17)	7 (14)	-
1-2	7 (19)	14 (27)	3 (27)
2-3	7 (19)	7 (14)	3 (27)
3-4	4 (11)	5 (10)	2 (18)
4-5	3 (8)	6 (12)	-
>5	2 (6)	3 (6)	1 (9)
Role in organization			
Owner or Operator	3 (8)	6 (11)	-
CEO	1 (3)	-	-
Executive Director	1 (3)	3 (6)	-
School Official	2 (6)	2 (4)	2 (18)
Farm Manager	1 (3)	5 (10)	2 (18)
Educator	15 (42)	25 (47)	3 (27)
Employee	1 (3)	12 (23)	1 (9)
Consultant	2 (6)	2 (4)	1 (9)
Volunteer	1 (3)	1 (2)	1 (9)
Other	1 (3)	9 (17)	-

Target audiences

Respondents were asked which groups they targeted with educational activities. While respondents primarily educated their students, many educators also targeted secondary audiences. Respondents from K-12 schools delivered educational and outreach activities to students in the following percentages by grade level: 11th-12th grades (56%); 9-10th grades (47%); 6-8th grades (36%); 5th grade and younger (36%). In addition, over a quarter (28%) of K-12 respondents targeted all ages, including both working-age adults and retirees, with their education and outreach activities. Respondents from colleges and universities primarily targeted undergraduate and graduate students, but nearly half (47%) of all college and university respondents also targeted working-age adults in addition to students, and 20% targeted K-12 students. Respondents from vocational and technical schools primarily targeted students at these schools, but 27% also targeted working-age adults.

Subjects taught using aquaponics

Respondents were asked to select from a list of 16 subjects, including the subject of aquaponics, which they taught using aquaponics in the past 12 months. Figure 1 presents the 10 subjects taught most frequently by school type. At K-12 schools, respondents used aquaponics to teach a wide range of subjects: aquaculture, agriculture, biology, chemistry, environmental sciences, earth sciences, and food systems. In colleges or universities, aquaponics was the main subject taught, but other science, engineering, and agriculture subjects were also included. Vocational or trade schools taught a narrower range of subjects, with aquaponics being the primary subject taught. Aquaponics was also used for self-guided research projects at (80%) of all institutions surveyed, with K-12 schools and colleges and universities using aquaponics systems more frequently for self-guided projects than vocational schools.

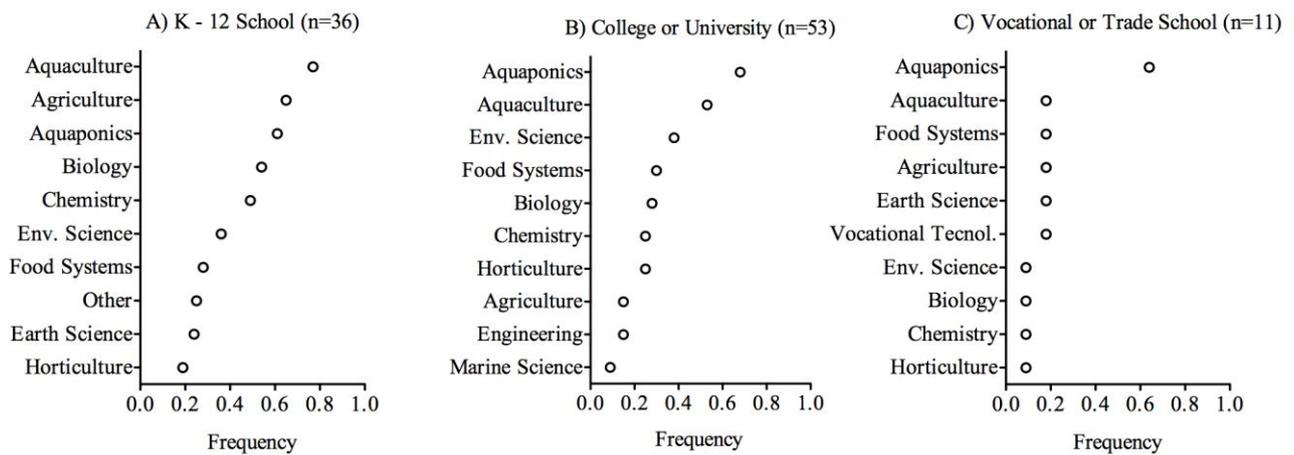


Figure 1. Frequency of subjects taught that incorporate aquaponics, by respondent organization.

Educational system and leadership

The majority of respondents felt that aquaponics was integrated into their curriculum, with the highest proportion of vocational/trade school respondents (78%) reporting curriculum integration and the lowest proportion of colleges and university respondents reporting curriculum integration (60%). Seventy one percent of K-12 respondents felt that aquaponics was integrated into their curriculum. Respondents reported a high degree of support from their institution leadership (89% for K-12 school respondents, 86% for college and university respondents, 100% for vocational and technical school respondents).

Participants in tours, classes, courses and workshops

The survey collected data on the number of participants in aquaponics-related lessons, tours, workshops or courses per institution per year as a categorical variable (e.g., 1-24, 25-49, 50-99, etc. participants/year). The range of total participants per year was estimated by summing the upper and lower bounds for each response. We estimate that a total of 12,320 to 50,250 participants/year were involved in lessons, tours, or workshops using the schools' aquaponics systems. More accurate values for participants could be achieved by asking respondents to report continuous data on numbers of participants instead of categorical data. Colleges and universities saw the most participants/year, with a median number of participants ranging from 100-499; K-12 and Vocational/Trade schools both saw a median number of participants ranging from 50-99 (Table 2).

Table 2. Estimated number of participants taught per year at aquaponics facilities or classrooms

Organization	N	Median	Range of total participants per year
College or University	53	100 - 499	9,530 - 39,600
K-12 School	36	50 - 99	2,310 - 9,060
Vocational or Trade School	11	50 - 99	480 - 1,590

Technical knowledge of respondents

Respondents were asked to rate their knowledge of various aspects of maintaining an aquaponics system on a Likert scale of 1-5, with 5 representing “strongly agree” and 1 representing “strongly disagree.” Across all school types, respondents “strongly agreed” that they knew how to modify the pH in the system and make repairs to plumbing. Respondents also “agreed” that they knew how to track fish growth rates, manage plant pests, and diagnose plant nutrient deficiencies. Respondents were less confident in their knowledge of regulations surrounding processing or selling fish.

Resources for technical assistance

Respondents were asked what resources they use to troubleshoot and solve problems related to their aquaponics operation (Table 3). Respondents used the Internet (*i.e.*, websites, community forums, and YouTube) more frequently than any other means to troubleshoot and solve problems. Respondents contacted other practitioners more often than government agencies, university staff or agriculture extension offices that work on aquaculture or aquaponics. Over half of respondents also attended aquaponics seminars or workshops.

Table 3. Estimated number of participants taught per year at aquaponics facilities or classrooms

Respondents' organization	N	Proportion of respondents using resources							
		Internet websites	Contact other growers	Print resources	University staff, agriculture extension	Seminars, workshops	State govt agencies	Federal govt agencies	Other
K - 12 School	36	0.89	0.83	0.69	0.50	0.50	0.22	0.11	0.06
College or University	53	0.83	0.60	0.74	0.74	0.53	0.15	0.15	0.02
Vocational or Trade School	11	0.91	0.55	0.64	0.55	0.55	0.36	0.09	0.09

Size of system and location

Aquaponics systems at K-12 schools were smaller than those at college, university, and vocational schools. The median size of K-12 school systems held 1,500 L of water and occupied 19 m² as compared to 2,200 L gallons (32 m²) at colleges and universities and 1,900 L gallons (70 m²) at vocational and technical schools. K-12 systems ranged from tabletop-scale systems at 75 L, to mid-sized systems with 7,900 L, while college, university, and vocational systems had a much greater size range with the largest college system containing 150,000 L. Across all school types, just over half (55%) of all respondents sited at least part of their system in a greenhouse, while 40% sited at least part of their system indoors. Only 31% had outdoor components to their system.

Investments in aquaponics

Schools made a wide range of investments in their aquaponics facilities, from none to over \$500,000 US dollars. The median amount of money invested by a K-12 school, college or university, and vocational or technical school in their aquaponics facility was \$1,000 to \$4,999 US dollars/year. Overall, we estimate a total of \$1.4 to \$4.3 million was invested in aquaponics by all schools in the study during the previous 12 months, which was calculated by multiplying the minimum and maximum value in each category by the number of responses. Collectively, by type of school, colleges and universities in the study spent \$1.1 to \$3.2 million on their systems in the previous year, vocational and trade schools spent \$0.13 to \$1.1 million, and K-12 schools spent a total of \$0.13 to \$0.41 million (Figure 2).

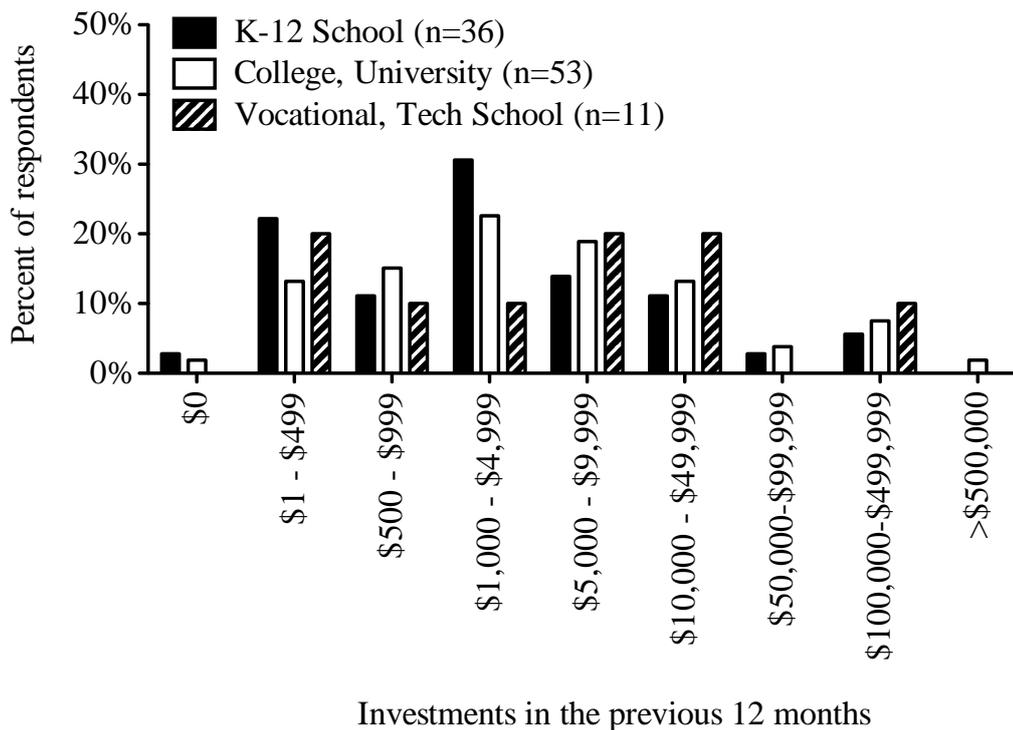


Figure 2. Aquaponics investments by respondent in US dollars.

Funding sources

In the previous 12 months, respondents at K-12 schools financed their operations with government funding or grants (42%), non-governmental (NGO) funding sources including grants and gifts (22%), and income from the sale of aquaponics products, materials, workshops and consulting (14%). Among respondents at colleges and universities, 51% financed their operations with governmental funding, 25% received NGO funding, and 26% used income from the sale of aquaponics products, materials, workshops and consulting. A larger proportion of vocational and technical school systems were supported by income from the sale of aquaponics products, materials, workshops and consulting (used by 36% of respondents) compared to other academic institutions, and they had lower rates of governmental funding (27%).

DISCUSSION

Aquaponics in education exists at a frequency and scale much greater than the few documented examples might suggest. Schools across the United States, and likely other countries, are using aquaponics as a tool to reach tens of thousands of students and working-age adults in a way that can complement the growth of school gardens. In general, subjects taught using aquaponics systems focused more exclusively on STEM topics and targeted older age groups than many soil-based school gardens. Aquaponics education was popular at both the college level and among K-12 schools, indicating that it is a technology that can be used to reach a wide age range. Surprisingly, many schools, particularly colleges and universities, were using their aquaponics systems to reach populations outside of their student body, indicating that aquaponics could provide a vehicle for community outreach for academic institutions.

K-12 schools

Aquaponics education in K-12 schools is science-focused, project oriented, and geared primarily towards older students, setting it apart from the typical soil-based school garden. Aquaponics education in K-12 schools primarily targets high school students, predominately in 11th and 12th grade, and educators use the systems to teach a broad range of science subjects such as biology, chemistry, or agriculture. By contrast, the literature on soil-based school gardens reveals a focus on grades 8 and younger, and in addition to science courses, the gardens are also used to teach nutrition or humanities such as language arts (Williams & Dixon, 2013; Graham, Beall, Lussier McLaughlin, & Zidenberg-Cherr, 2005). Most K-12 aquaponics educators also used the aquaponics system as a venue for student research projects. Aquaponics education offers K-12 educators a technology-centric alternative to soil-based school gardens, and provides science-focused experiential learning opportunities for older students. In US states that adopt the Next Generation Science Standards, schools can also use aquaponics education as a tool to meet the new standards by providing a platform for project based learning opportunities that can help integrate cross cutting concepts with scientific and engineering practices. Aquaponics systems at K-12 schools were generally smaller than systems at colleges and universities or vocational schools. The cost of entry for aquaponics in the classroom was typically less than \$5,000 US dollars, and the average system size was 1,500 L, larger than a countertop system, but still small enough to fit in a classroom. Unlike soil-based gardens, aquaponics systems can be sited indoors, in greenhouses and in small spaces, offering year round access to the system and versatility for schools that may not have suitable outdoor spaces. These advantages must be weighed against the greater need for technical knowledge for some educators.

Colleges and universities

Respondents from colleges and universities used aquaponics to teach a wide-range of science subjects and for self-guided research projects. Interest in aquaponics among colleges and universities parallels renewed interest in agriculture programs and teaching farms at institutions of higher learning. While many land-grant colleges are working to shift their focus back to teaching agriculture through demonstration, campus farms and sustainable food initiatives are also developing at private institutions throughout the country (Mazurkewicz, Harder, & Roberts, 2012; Barlett, 2011). In general, college and university aquaponics systems were larger and less integrated into the curriculum. Interdisciplinary subjects such as food systems and environmental science were

taught using the aquaponics system more frequently at colleges and universities than they were at other school types, where the focus was more often on single discipline subjects such as chemistry or biology. Colleges and universities attracted more participants than any other facility type, including working-age adults and K-12 students, who do not attend the institution. This indicates that these programs can be used as vehicles for education and outreach to the broader community.

Vocational and technical schools

Interestingly, while aquaculture has traditionally been taught at agriculture or vocational schools, only 11% of survey respondents represented vocational or tech schools. This low number may be due to the fewer number of vocational and technical schools overall compared to colleges and K-12 schools or our recruitment methods (see below). These institutions had notable differences compared to other schools. Vocational and technical schools invested more funds in their aquaponics systems and generated a greater proportion of their funding through sale of products produced in the aquaponics system. In general, the vocational school aquaponic systems were larger than those at K-12 schools, and displayed a very different pattern of subjects taught. Few vocational and technical schools used aquaponics systems to teach subjects other than aquaponics, indicating that for these educators aquaponics is a stand-alone subject and not a vehicle to address other STEM or food system topics. However, vocational and technical school respondents had a similar level of prior experience with aquaponics to the overall study population, indicating that aquaponics in the classroom is still relatively new for these institutions.

Respondents' knowledge

Implementing aquaponics in classrooms is not without challenges; Hart, Webb, and Danylchuk (2013) report that technical difficulties, lack of experience and knowledge, and maintenance over holidays and vacations can pose significant barriers to teachers using aquaponics in education. The lack of knowledge and experience is also reflected in the common challenges to soil-based school gardens. In a survey of California principals in schools with a garden, Graham et al (2005) report that lack of a teacher's interest, knowledge, experience, and training were a barrier to successfully using the garden for academic instruction for 70% of respondents. The technical and interdisciplinary nature of aquaponics would increase the importance of knowledge and experience for educators practicing aquaponics. Most respondents to our survey were new to practicing aquaponics; the median respondent had less than or equal to three years experience. While we did not specifically ask about major challenges faced by respondents, when asked about their knowledge of six common aspects of operating a successful aquaponics system, most respondents across all school types felt confident in their abilities, despite limited experience. However, our survey only targeted educators who have operated aquaponics systems and not those who may have felt intimidated by various barriers.

The availability of trainings, resources, and mentors could help offset potential knowledge barriers. Hart, Webb, and Danylchuk (2013) reported that educators were in need of community connections and support in regards to aquaponics systems. We found that educators most often turned towards the Internet, other growers, and print resources for technical assistance with aquaponics, indicating that these methods were the most effective for obtaining information.

Limitations

The data for this analysis were taken from a larger survey of aquaponic growers, including those not involved in education, such as hobbyist and commercial farmers. As a result, our recruitment was focused on aquaponics organizations rather than schools, potentially leading to us missing some educators. Because of this recruitment method, we captured educators who were already engaged in an aquaponics network, perhaps leading to respondents having more confidence in their knowledge than educators who are not engaged with similar networks. Despite this limitation, we have captured a broad range of respondents representing a variety of academic institutions and geographic locations.

The impact of aquaponics on academic outcomes was beyond the scope of this research; however, there is a need for future work that examines how aquaponics in education affects academic outcomes, and in particular, how those outcomes compare to those of soil-based school gardens. As school gardens continue to spread, this technical alternative offers teachers a way to reach older student age groups and incorporate additional topics, including STEM subjects and student led research.

CONCLUSION

This study is the first survey to present the demographics, target audiences, educational focus, experience, and funding sources of aquaponics educators in the US. These results are informative and can serve as a baseline for comparing future research and applied in other countries besides the US. Aquaponics is an emerging educational technology, and many participating educators are new to aquaponics, indicating a potential need for more training and technical support among educators. Aquaponics education is active in a variety of settings, with a range of investments and facility sizes. Continued collaboration and knowledge transfer among aquaponics educators and supporting organizations could enable the diffusion of best practices in education.

ACKNOWLEDGEMENT

This work was funded by the Johns Hopkins Center for a Livable Future with a gift from the GRACE Communications Foundation who had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

REFERENCES

- Barlett, P. (2011). Campus sustainable food projects critique and engagement. *American Anthropologist*, 113(1), 101- 115. <http://dx.doi.org/10.1111/j.1548-1433.2010.01309.x>
- Caldwell, J. (1998) Why use aquaculture as an educational tool? The Conservation Fund's Freshwater Institute, Shepherdstown, WVA
- Eatmon, T.J., Szymecki, S., Varrato, A. (2012). Aquaponics Update. *Allegheny College Civic Engagement Newsletter, Spring 2012*. Retrieved from <http://sites.allegheny.edu/civicingagement/civic-engagement-newsletter/aquaponics-update/>
- Frederick, J.A. (2005). Science in action: Tools for teaching urban aquaculture concepts. In B. Costa-Pierce, A. Desbonnet, P. Edwards, & D. Baker (Eds.), *Urban Aquaculture* (233-246). Cambridge, MA: CABI Publishing.
- Graham, H., Beall, D.L., Lussier, M., McLaughlin, P., Zidenberg-Cherr, S. (2005). Use of school gardens in academic instruction. *Journal of Nutrition Education and Behavior*, 37(3), 147-151.

- Hart, E., Webb, J., & Danylchuk, A. (2013). Implementation of aquaponics in education: An assessment of challenges and solutions. *Science Education International*, 24(4), 460-480.
- Johanson, E. (2009). Aquaponics and hydroponics on a budget. *Tech Directions*, 69(2), 21-23.
- Love, D.C., Fry, J.P., Genello, L., Hill, E.S., Frederick, J.A., Li, X., & Semmens, K. (2014). An international survey of aquaponics practitioners. *PLoS ONE*, 9(7): e102662. <http://dx.doi.org/10.1371/journal.pone.0102662>
- Maryland Sea Grant. (2014). *K-12 Aquaculture Education*. Retrieved from <http://www.mdsg.umd.edu/topics/k-12-aquaculture-education/k-12-aquaculture-education>
- Mazurkewicz, M., Harder, A., & Roberts, T.G. (2012). Evidence for experiential learning in undergraduate teaching farm courses. *Journal of Agricultural Education*, 53(1), 176-189. <http://dx.doi.org/10.5032/jae.2012.01176>
- Morgan, S. C., Hamilton, S.C., Bentley, M.L., & Myrie, S. (2009). Environmental education in botanic gardens: Exploring Brooklyn's botanic garden project's green reach. *Journal of Environmental Education*, 40(4), 35-52.
- Nelson, R. (2007). Ten great examples of aquaponics in education. *Aquaponics Journal*, 46, 18-21.
- Parmer, S. M., Salisbury-Glennon, J., Shannon, D., & Struempler, B. (2009). School gardens: An experiential learning approach for a nutrition education program to increase fruit and vegetable knowledge preference and consumption among second grade students. *Journal of Nutrition Education and Behavior*, 41(3), 212-217. <http://dx.doi.org/10.1016/j.jneb.2008.06.002>
- Soares, S., Buttner, J., & Leavitt, D. (2001). *Aquaculture curricula guide: A resource tool for the aquaculture educator*. North Dartmouth, MA: Northeast Regional Aquaculture Center.
- Wingenbach, G. J., Gartin, S.A., & Lawrence, L.D. (1999). Students perceptions of aquaculture education in the northeast region, *Journal of Agriculture Education*, 40(1), 14-22. <http://dx.doi.org/10.5032/jae.1999.01014>
- Wardlow, G., Johnson, D.M., Mueller, C.L., & Hilgenberg, C.E. (2002). Enhancing student interest in the agricultural sciences through aquaponics. *Journal of Natural Resources and Life Science Education*, 31, 55-58.
- Williams, D.R., & Dixon, P.S. (2013). Impact of garden based learning on academic outcomes in schools. *Review of Educational Research*, 83(2), 211- 235. <http://dx.doi.org/10.3102/0034654313475824>